BRITISH WELDING JOURNAL

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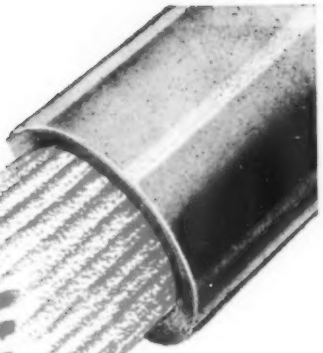
By T. M. Charlton

Discussion at Autumn Meeting 1958

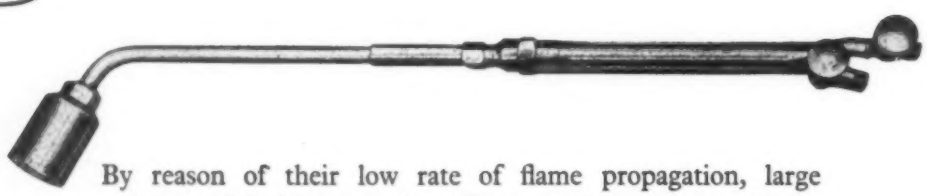
the new B.I.G.



INTENSE HEAT

Propane Heating Torch

HARRIS DESIGN



By reason of their low rate of flame propagation, large volumes of fuel gases such as Propane, Pyrogas, etc., can be safely mixed with Oxygen without the danger of the flame back-firing. The larger the volume of gases mixed, the greater the flame and the resulting heat value. The new B.I.G. PROPANE Heating Torch uses this principle with truly remarkable results.

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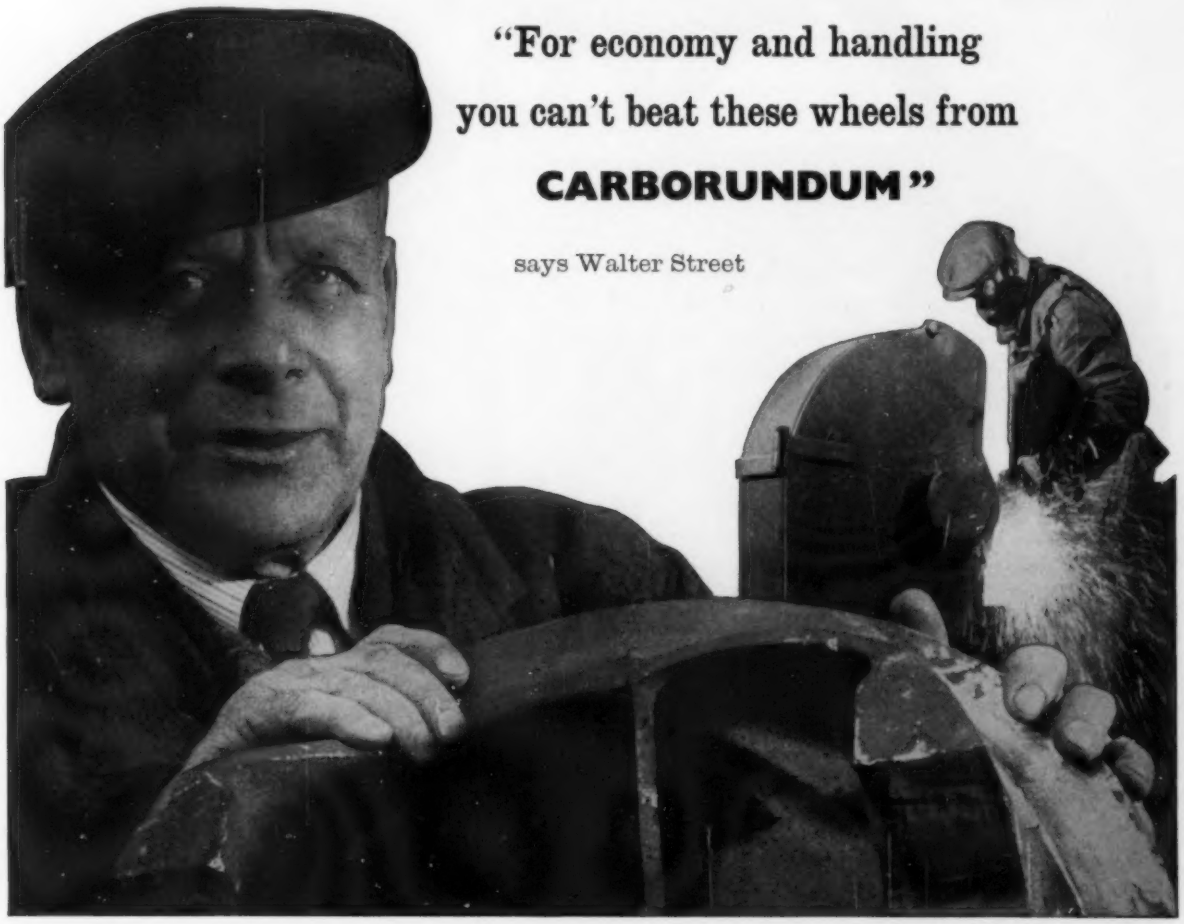
Inside front cover

CUSTOMERS OF CARBORUNDUM

Leys Malleable Castings, in Derby, is one of the biggest foundries in the country, and they've been using CARBORUNDUM'S wheels since 1927. We spoke to foreman Wat Street, who has been there a good 36 years. Pointing to a batch of gear housings, Wat said: "We're proud to export such well-fettled products. These wheels from CARBORUNDUM stand up to heavy feeder removal and cut-out, yet they wear from 36" to 15½" without losing their sharp grinding corners. We're not exactly gentle on the wheels, but any of the men will tell you that you can't beat them for durability and easy handling."



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says Walter Street

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In most of the major industries of the world, CARBORUNDUM is helping top firms to make better products, to cut costs, and to speed production. In the sharply competitive industrial climate of today there are three main conditions for success: high quality, low prices, and early deliveries. CARBORUNDUM can help you to meet them all.

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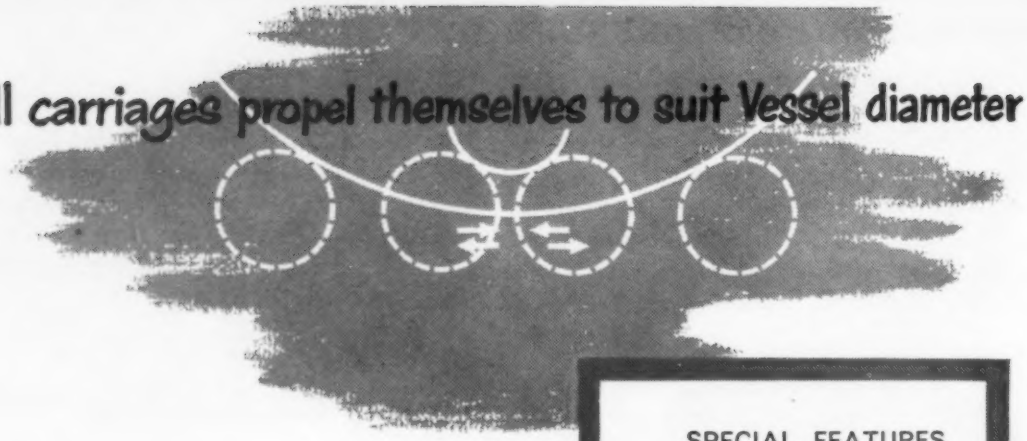
TRADE MARK

can cut your costs

Roll carriages propel themselves to suit Vessel diameter



This new Heavy Duty Rotator incorporates the *exclusive* feature whereby the Roll Carriages propel themselves along the main frame to accommodate different diameter vessels. The carriages when positioned fall into positive locations and the need for carriage fixing bolts is eliminated.

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- ★ Self Propelled Carriages, no manual adjustment.
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- ★ Internal gear Drive, giving exceptional vessel projection clearance.
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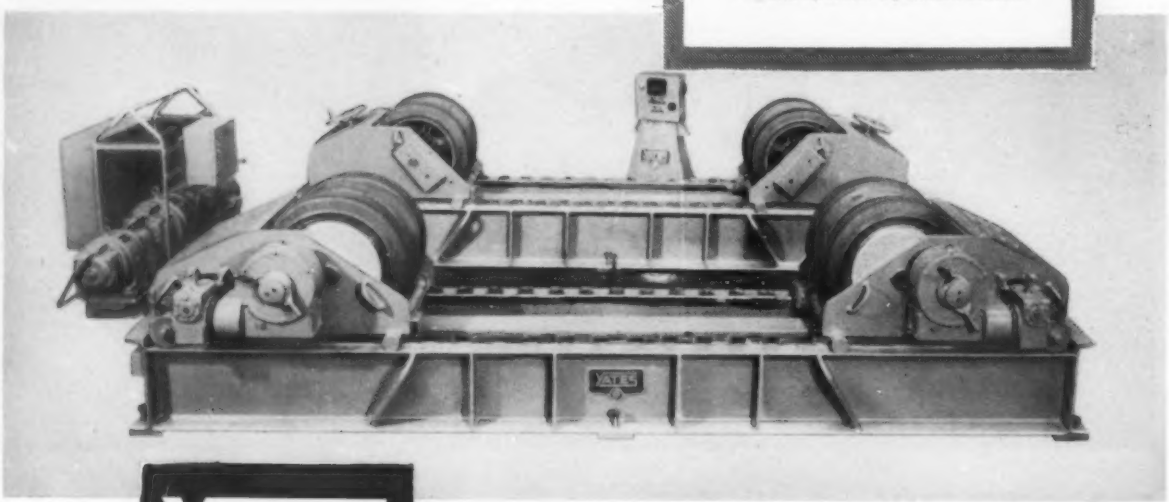

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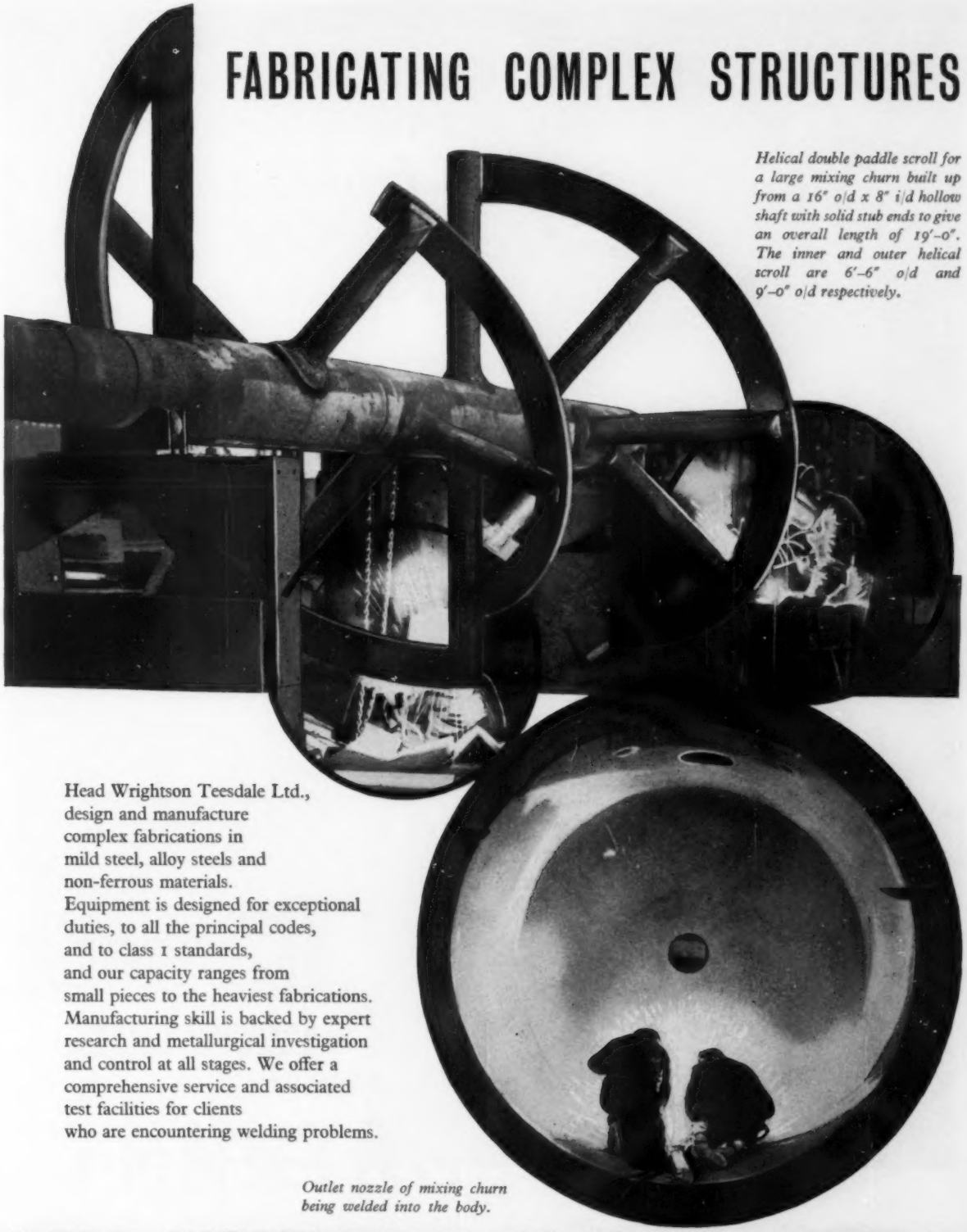

Helical double paddle scroll for a large mixing churn built up from a 16" o/d x 8" i/d hollow shaft with solid stub ends to give an overall length of 19'–0". The inner and outer helical scroll are 6'–6" o/d and 9'–0" o/d respectively.

Head Wrightson Teesdale Ltd., design and manufacture complex fabrications in mild steel, alloy steels and non-ferrous materials. Equipment is designed for exceptional duties, to all the principal codes, and to class 1 standards, and our capacity ranges from small pieces to the heaviest fabrications. Manufacturing skill is backed by expert research and metallurgical investigation and control at all stages. We offer a comprehensive service and associated test facilities for clients who are encountering welding problems.

Outlet nozzle of mixing churn being welded into the body.

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TEESDALE IRON WORKS THORNABY-ON-TEES

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P.1482

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Model 185799 has a continuous hand welding current range of 50-250 amps, with a maximum intermittent current of 333 amps.
The larger set, model 185800, has a current range of 75-350 amps, with a maximum intermittent current of 450 amps.

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The moving-coil regulator gives infinitely variable adjustment of welding current over the whole range without the use of tappings.

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Sets are air cooled, making fire risk negligible.

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All working parts are easily accessible.

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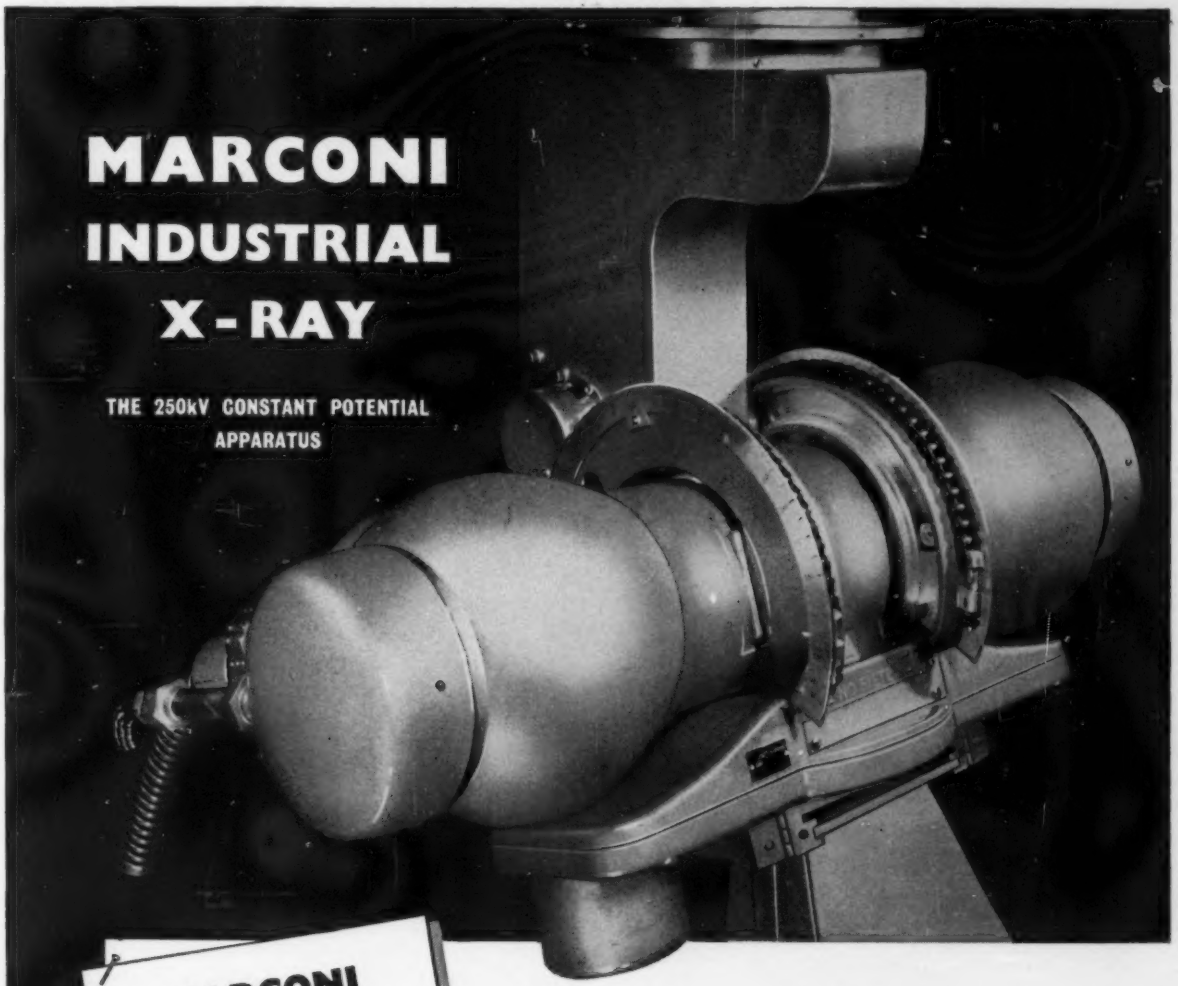
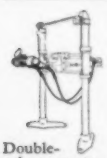


MARCONI for X-Ray

SOME MOUNTINGS FOR THE 250-kV TUBEHEAD *

Telescopic-suspension tubehead mounting



Double-column gantry tubestand

Dual-travel tubestand

* *Let Marconi engineers help you in your choice of mountings. In addition to those shown, other tubehead mountings are available to suit specialized requirements. Full details gladly sent on request.*

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The Kilovoltage range—which is from 30 to 250 kV in 2-kV steps—permits examination of components varying from plastic and aluminium items to ferrous sections more than three inches thick.

The scope of the apparatus has been extended still further by the development of a comprehensive range of tubehead mountings, which includes fully mobile and semi-mobile units, and suspension and static tubestand types, some of which are shown on the left. These mountings have been designed to meet industrial requirements and Marconi engineers are always available to recommend the most suitable installation, or suggest adaptations. For preliminary details of the Marconi 250 kV Constant Potential X-Ray equipment, please write for leaflet AQ22.

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Telephone: 1408

North:
23/25 Station Square, Harrogate
Telephone: 67455

Export Department: Marconi Instruments Ltd., St. Albans, Herts. Telephone: St. Albans 56161

DX22

Photograph illustrating the FUSARC/CO_2 process by courtesy of Quasi-Arc Limited

The use of low pressure CO_2 gas as an inert shield in the welding of steels is increasing. CO_2 is not only cheap — it enables high quality welds to be made in the shortest time.

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A TOUGH ASSIGNMENT . . .

The main photo shows a close-up of a Tubular Steel Production Tower built by the Eonit Engineering Co. Ltd. and welded throughout with Rockweld Electrodes. For use in the Persian Gulf, this tower forms part of a construction which will replace the drilling rig shown above if oil is found

Again ROCKWELD

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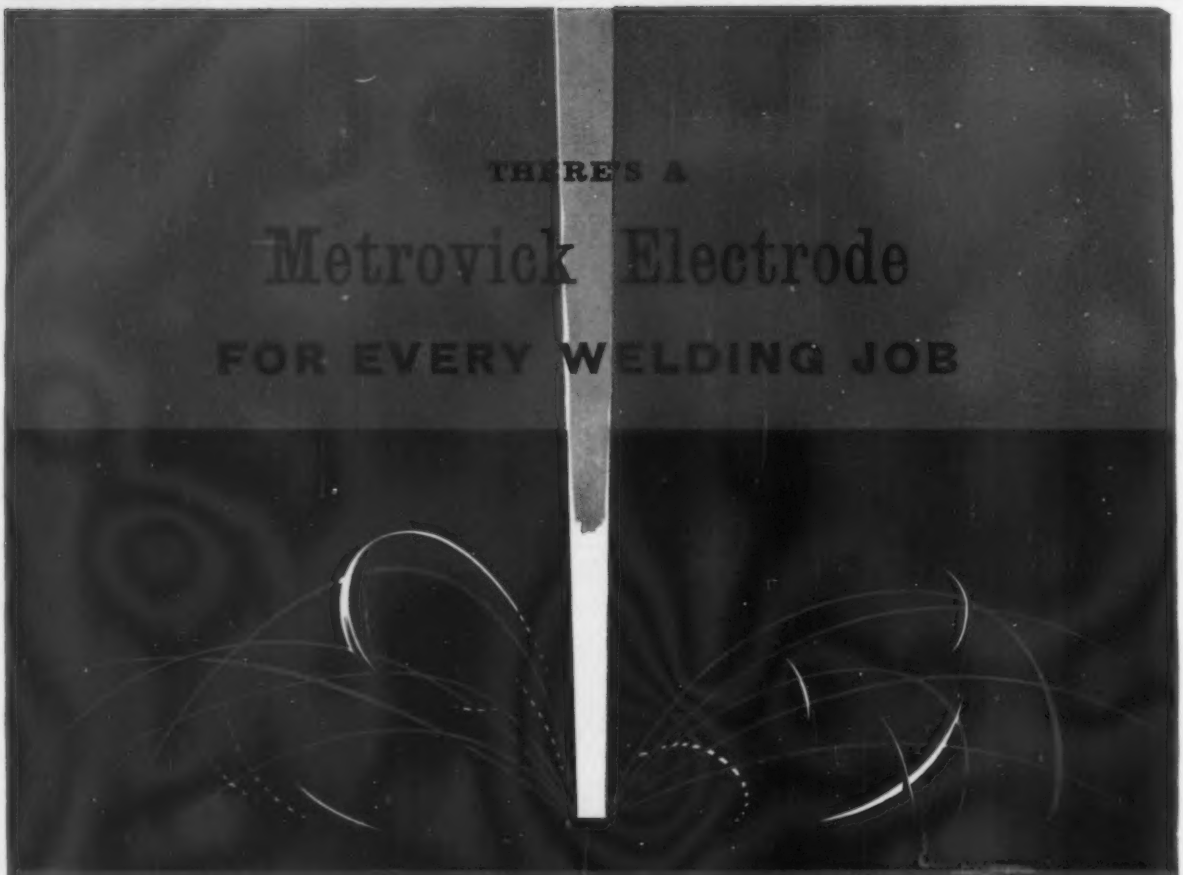

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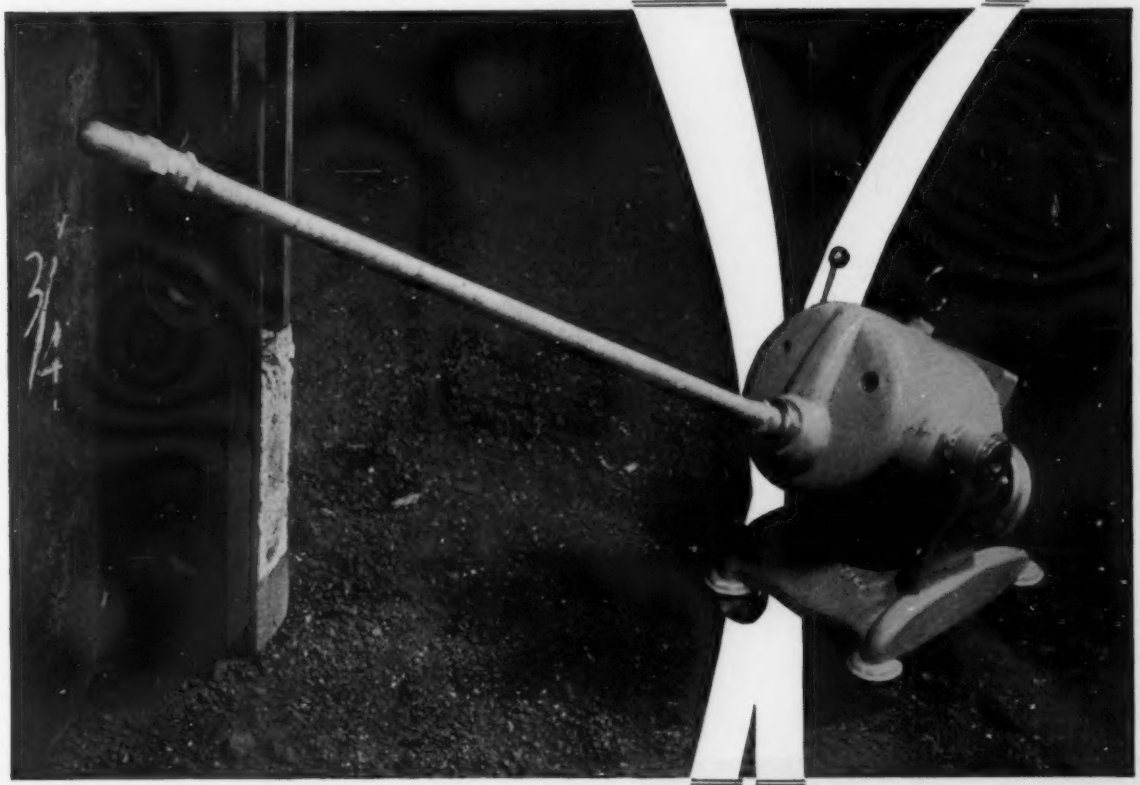

RADIOACTIVE CAESIUM SOURCES are being increasingly used as an alternative to X-ray equipment for the radiographic examination of castings, welds etc. Equipment containing caesium sources is compact, portable, easy to use and gives good results using standard radiographic techniques. It needs no maintenance and can be used in conditions unsuitable for X-ray machines. Gamma-ray sources for this equipment are inexpensive and are supplied by The Radiochemical Centre in a wide range of sizes. Besides Caesium-137, sources containing other radioisotopes, thulium, iridium and cobalt, are available.

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Further details of these sources will gladly be supplied on request to:

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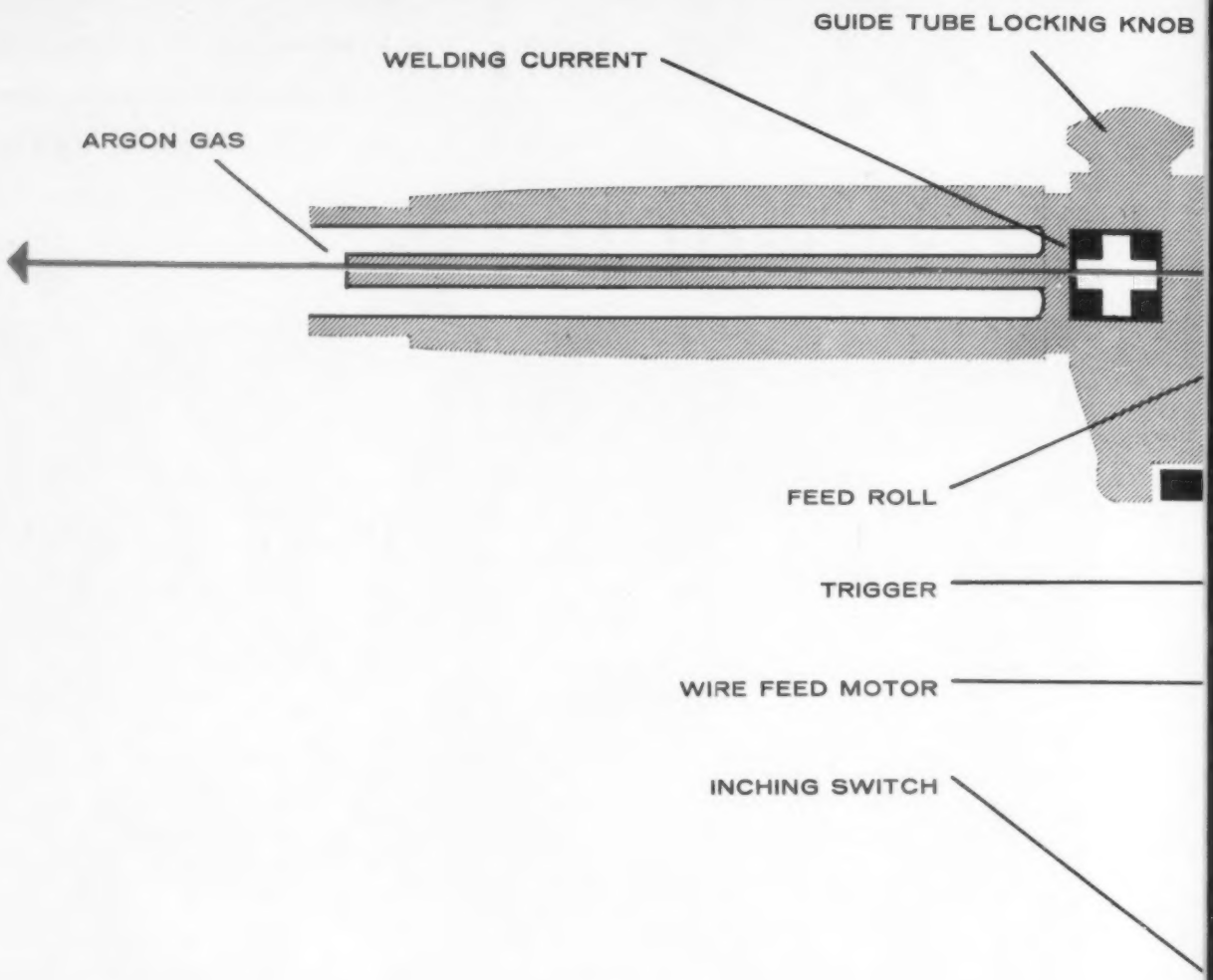

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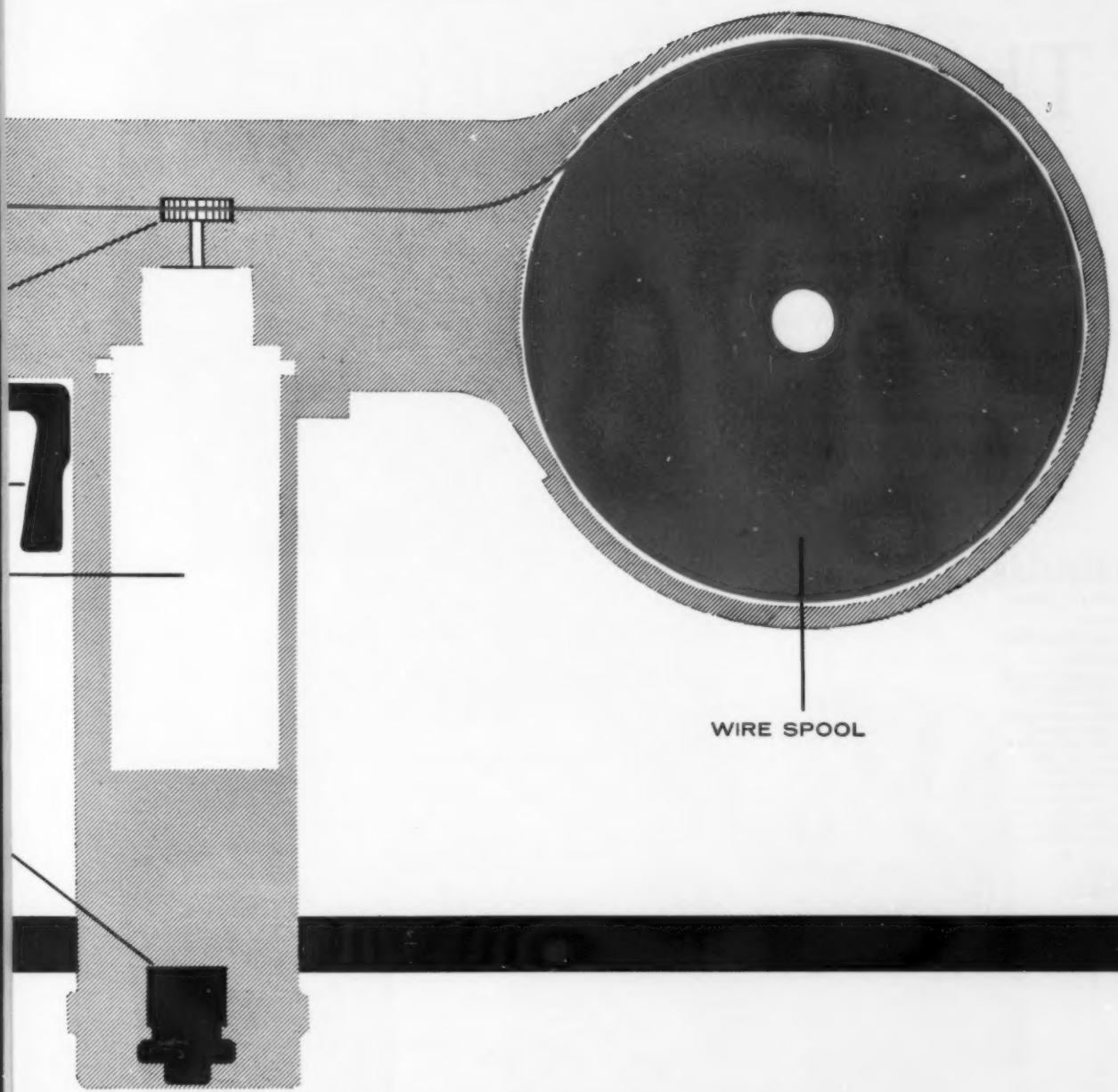
- Once wire-feed speed has been set on control unit (supplied as standard fitting with 30 ft. leads to gun) all functions —

Quasi-Arc



speed in thin wire welding

wire feed, argon flow, etc. — are operated by trigger on gun.
- Inching button for optimum arc striking characteristics.
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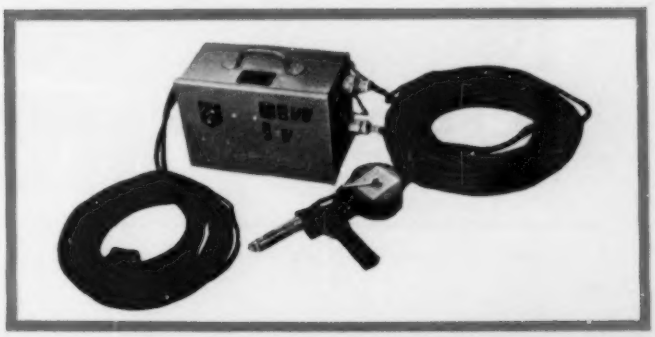
For full technical information on SIGMETTE, write to Quasi-Arc Limited, Bilston, Staffs.



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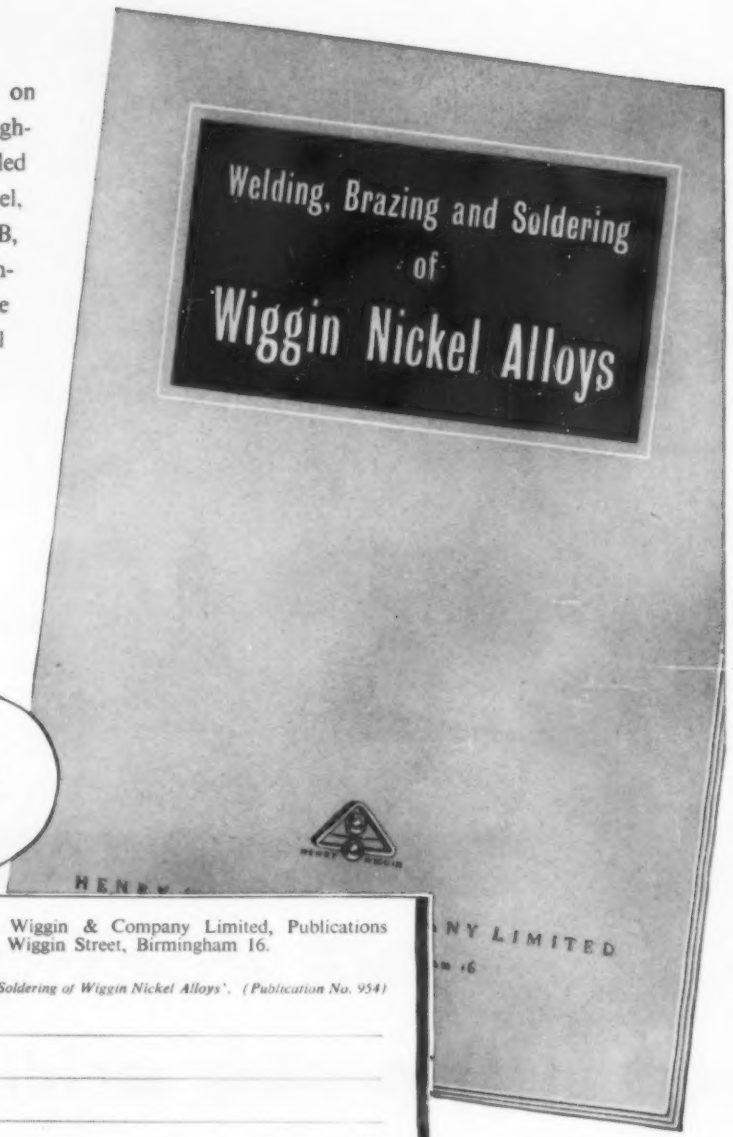

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at Hatfield Technical College on "Wiggin Nickel Alloys in Industry"
All engineers should see this exhibition of nickel alloys for heat and corrosion resistance and other applications in Industry. Exhibition at Hatfield Technical College Hatfield, Hertfordshire, on 17th—18th November (10 a.m. to 8 p.m.) and 19th November (10 a.m. to 4 p.m.) Admission free

Copies will gladly be sent on request

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Please send me a copy of 'Welding, Brazing and Soldering of Wiggin Nickel Alloys'. (Publication No. 954)

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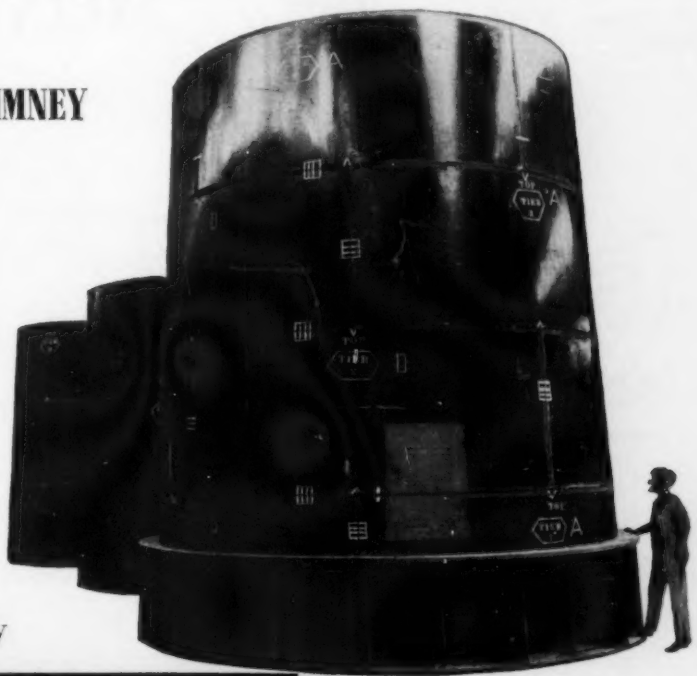
To Venezuela BOOTHS of BOLTON have recently shipped a 150 ft high steel chimney stack to be erected at a Power Station for C.A. Energia Electrica de Venezuela. Some of the sections of this self-supporting stack assembled at Hulton Lane for proving before shipment are seen in this photograph. Overall height, 150 ft; diameter, 10 ft 6 in.; lower 70 ft length widening to 17 ft diameter at base. Weight 52 tons.



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BK 42A	600	56	Integral
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Welding
TECHNOLOGY

A New Electro-Slag Welding Process

By D. J. W. Boag, B.SC., A.M.I.MECH.E., A.M.I.E.E., *and W. K. B. Marshall*, B.ENG., F.I.M.

A description is given of the Rockweld-Vus 'Vertomatic' electro-slag welding machine. This differs from the Russian machines in having articulated water-cooled shoes, automatic control of the shoe motion and flux feed, and in using a special composite wire.

Factors affecting weld-metal properties are discussed in detail. The process appears to give welds of acceptable properties in the as-welded or stress-relieved conditions.

With technological progress there has inevitably been an increasing demand for heavier welded fabrications. Pressure vessels, alternator casings, press frames, rolling mill housings and, more recently, reactor vessels for nuclear power stations often require the welding of steel plate 2 in. thick and upwards. On economic grounds, welds of such dimensions clearly call for the application of automatic methods and provided that the conditions are favourable they do, in fact, readily lend themselves to the application of such methods. The very thickness of the sections involved permits the use of very heavy currents and makes the use of automatic welding more attractive. However, with the traditional automatic methods—the submerged-arc process and the open-arc continuous-wire process—the work must normally be manipulated so that the weld can be done in the flat position. The very large weld pool arising from the use of heavy currents gives very little latitude in this connection and this has in the past perhaps been one of the major factors limiting the further application of automatic welding in this field. With large items it is not always possible to manipulate the job, and certainly in site welding, all vertical welds, irrespective of the thickness of plate involved, have been done manually.

It is rather more than ten years ago that the Russians had the idea of controlling the molten slag and weld metal in the vertical position by means of water-cooled copper shoes. It is very probable that the early experiments were an attempt to carry out submerged-arc welding in the vertical position, and it is understandable that this should lead to the development of the electro-slag process where the source of heat is the energy released during the passage of current through a liquid slag medium rather than through a gaseous medium as in the conventional submerged- and open-arc processes. The energy released in the slag melts both the electrode wire and the edges to be welded.

In Russia, electro-slag welding has been developed so successfully that, although starting originally as merely a vertical welding process, it has now become the preferred method of welding thick plates. It is found worthwhile, whenever possible, to manipulate the work so as to permit the application of the process even when the alternative exists of welding by the submerged-arc process in the flat position.

Principle

The process is shown diagrammatically in Fig. 1. The plates to be welded are set up so that the edges, which may be flame-cut or machined, form a parallel vertical gap $\frac{3}{4}$–$1\frac{1}{2}$ in. wide depending on the thickness. It is usual to weld C clamps to the plates to hold them

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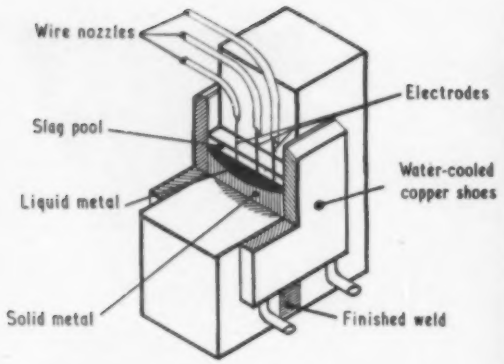
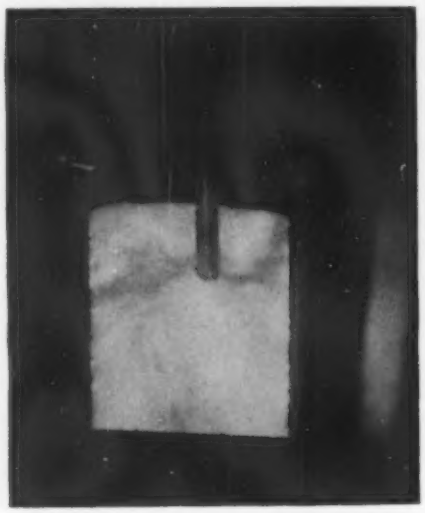
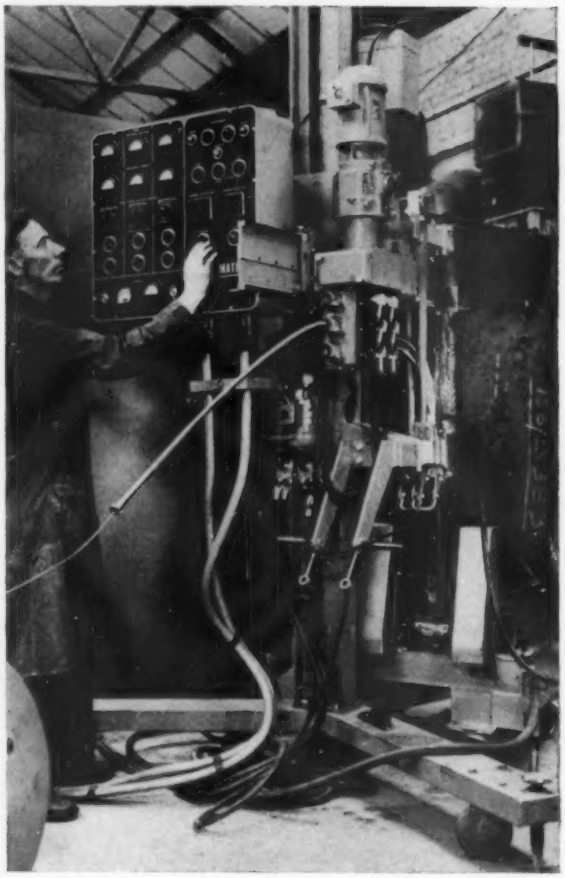
Mr. Boag is Managing Director, and Mr. Marshall Chief Metallurgist of Rockweld Ltd.



1—*Diagram of the electro-slag welding process*



2—*View of electrode wire entering molten slag bath*



3—*General view of Rockweld-Vus machine showing stand with control cabinet. (Producing the longitudinal weld in a 20 in. dia. cylinder of 2 in. thick boiler steel)*

in line and to maintain the appropriate gap. There are no close limits to this gap. Water-cooled shoes are positioned at the back and front of the gap so as to confine the molten weld metal and slag. Wire or wires forming the consumable electrodes are fed into the molten slag, and the heat generated by the passage of the current through the slag is sufficient to melt the wire and the edges of the plate. Figure 2 shows the wire entering the liquid slag bath. For starting the weld, a shaped starting block is used, and for the first few minutes of the operation the conditions are those of submerged-arc welding. When sufficient flux has been melted in this way, the change-over to electro-slag welding takes place automatically. The water-cooled shoes then commence to move vertically so as to contain the molten slag and weld metal as the weld progresses. The wire is usually made to oscillate slowly from the front to the back of the gap so as to distribute the heat more evenly.

It is not the intention, in this paper, to discuss the electro-slag process in any great detail. This has already been done in the many Russian papers on the subject.* But there are certain aspects of the process which the Rockweld-Vus machine has been designed to exploit or control more effectively than did the original Russian machines, and these aspects will be given special attention.

The Rockweld Machine

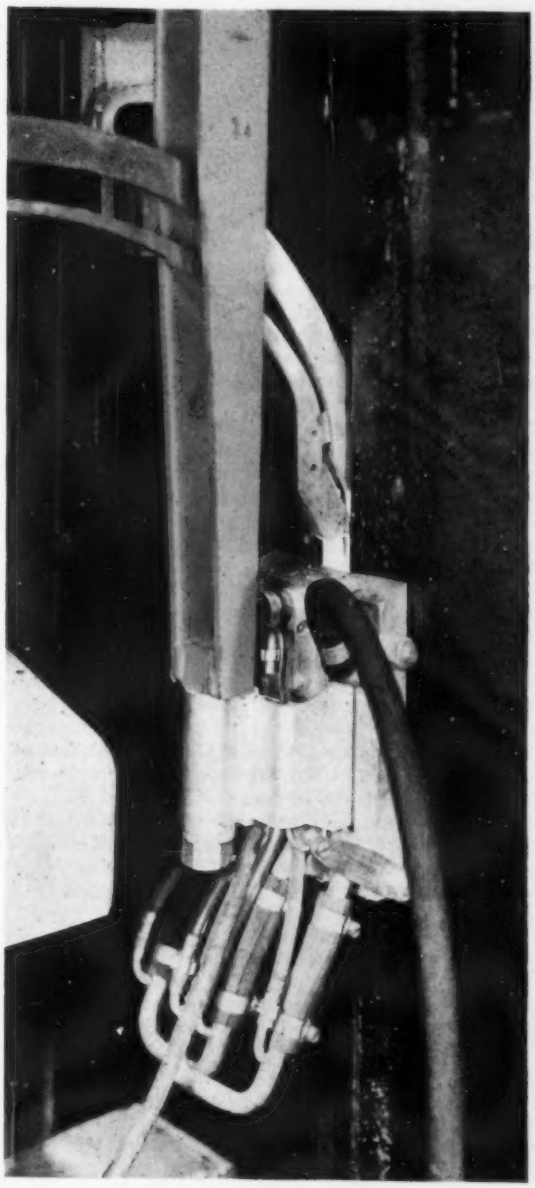
A general view of the Rockweld-Vus 'Vertomatic' machine is shown in Fig. 3. The machine represents a considerable advance on the simple system already described. It is itself a development of the Czechoslovakian version of the original Russian process, and incorporates several refinements aimed at increasing flexibility and improving the quality and consistency of the deposited weld metal.

Firstly, the water-cooled copper shoes each comprise three articulated sections so that a certain

*See for example: A. M. Makers, Yu. M. Gotalski and V. F. Grabin: *Avto. Svarka*, 1955, vol. 8, pp. 11–25; and G. Z. Voloshkevich: *Avto. Svarka*, 1958, vol. 11, pp. 12–17.

amount of out-of-alignment or inequality in thickness between the two plates can be accommodated. The shoes will also accommodate plates bent to a radius as small as 20 in.; their use on a cylinder of this radius is shown in Fig. 4. For smaller radii special purpose shaped shoes must be used.

The second important refinement is that the vertical progress of the shoes, and in fact that of the whole of the welding head, is completely automatic and keeps pace exactly with the progress of welding. The operation of the control gear governing the progress of the shoes depends on the fact that the slag is, when molten, highly ionized and is therefore a good conductor of electricity, but when cooler, and in particular when it has solidified, it no longer conducts electricity. A water-cooled insulated probe projects through one of the shoes and makes contact with the thin layer of slag that is left between the copper shoes and the surface of the weld. The probe has the effect of putting this layer of flux in series with a relay circuit which operates the motor driving the pinion engaging with the vertical rack. When the shoes are high relative to the position of the weld pool, and thus the probe is in contact with a thin layer of molten or plastic flux, current flows through the circuit and breaks the current supply to the motor. The head thus pauses in its vertical progression until more weld metal has been deposited and the flux in contact with the probe has solidified. When this happens, current ceases to flow in the relay circuit thus closing the motor circuit and causing the shoes and welding head to advance vertically once again. The maximum length of weld that can normally be produced by the machine in one run is 15 ft.



4—Water-cooled copper shoes during welding of cylinder shown in Fig. 3

A third very important feature of the Rockweld-Vus machine is that it uses a special composite wire in place of the normal solid wire. This composite wire is fabricated from strip and contains a small amount of flux to make up in part for that consumed during welding. More important, however, it contains powerful deoxidizers which, as will be shown later, have the effect of giving good mechanical properties in the weld without recourse to normalizing. A composite wire of this sort also has the advantage that its composition can be readily changed to give any required adjustment of weld metal-composition. The normal diameter of the wire is $\frac{1}{8}$ in. and it is available in coils of up to 130 lb.

A fourth feature is the automatic control of the depth of the molten flux. As already mentioned, a proportion of the make-up flux is added *via* the wire, leaving a small proportion to be added from the flux hopper. These additions are controlled by a second probe, which is at a higher level than the first, and normally projects into the molten slag pool. When the probe makes contact with the molten slag in this way, current flows in a circuit operating a relay controlling the flux-hopper valve. Under normal conditions, no make-up flux falls into the slag pool, but if the slag level falls below the level of the probe, the circuit is broken and the flux-hopper valve opens, thus permitting a fresh supply of granulated flux to enter the weld pool until the level of the slag is again such that contact is made with the probe. The normal depth of slag is $1\frac{1}{4}$–$1\frac{1}{2}$ in.

Another feature of the Vertomatic electro-slag machine is the flexibility of adjustment to the reciprocating motion of the electrode. The amplitude of the reciprocation is controlled automatically by limit stops, whose positions are adjustable to give an amplitude varying from 0 to 5 in. The speed of cross-traverse is also infinitely variable between 15 and 80 in. per minute. Furthermore, the pause at each end of the reciprocating motion can be varied from 0 to 30 sec by means of a time relay. This wide flexibility of adjustment permits accurate control of the weld section.

The power supply for the 'Vertomatic' equipment is a specially developed transformer with a nominal

rating of 1,000 amp. It has controls which enable the form of the static characteristic to be varied from drooping to relatively flat over a range of open-circuit voltages from 40 to 80. Remote control of current, open-circuit voltage, and type of characteristic is achieved by relay-operated switches and a motorized moveable core in the transformer. This permits rapid and independent adjustment of current and voltage during the course of welding.

The head itself is designed to feed one, two, or three electrode wires simultaneously. Each wire requires its own individual transformer, and each power circuit can be controlled quite independently from the others. Normally one electrode is used for plate up to 5 in. thick, two for plate between 5 and 10 in., and three for plate between 10 and 15 in. The rate of wire feed is infinitely variable over the range 25–300 in./min.

5—Production of second longitudinal weld in cylinder shown in Fig. 3

Operation and Application

The electro-slag process can be used for the vertical welding of plates as thin as $\frac{1}{2}$ in., but it is doubtful if it is economic for thicknesses below about $1\frac{1}{2}$ in. There appears to be no obvious upper limit of thickness, and 14–15 in. is quite within the range of feasability of the Rockweld machine.

As already noted, the plates to be welded should be prepared with a square edge by flame-cutting or machining. It is also advisable to grind roughly by hand the surface of the plates for 2–3 in. in from the edge, so that the shoes will have no difficulty in sliding over this surface during their vertical progression. The plates are then set up so as to provide a vertical parallel gap of width depending on the thickness of plate. Thinner plate generally requires the narrower gap, with a range between $\frac{3}{4}$ and $1\frac{1}{2}$ in. Welded-on clamps are needed to hold this gap. A shaped starting block, which serves to extend the gap downwards, is welded at the bottom of the gap, and the shoes are placed in position on both sides of the slot in this block. A certain amount of granular flux is then put into the slot and an arc is struck as in normal welding. This submerged arc runs for a short time, and a considerable quantity of flux is melted. During this period the welding transformer is adjusted to operate with a drooping characteristic, but as soon as sufficient flux has been melted to allow the changeover to electro-slag welding, a selected flat characteristic is used.

From this moment, the operation of the machine is virtually automatic, provided that the correct settings of current, voltage and oscillation of electrode have been chosen. On a new application it may be necessary for the operator to make adjustments to these settings from time to time and also possibly to the slag depth, but on repeat work this should seldom be necessary. To facilitate completion of the weld, the gap should be extended upwards by welding on short side plates and the weld should be taken beyond the end of the main plates before the current is switched off. Figure 5 shows both the starting and finishing blocks on a longitudinal weld in a cylinder.

As a guide to typical operation, welding conditions for 2 in. plate are as follows:

Electrode	Single–$\frac{1}{2}$ in. dia. composite
Width of gap	$1\frac{1}{8}$–$1\frac{1}{4}$ in.
Current	500–540 amp
Voltage	42–44 V
Linear speed of oscillation of electrode	40–50 in./min
Depth of slag	$1\frac{1}{4}$–$1\frac{1}{2}$ in.
Average speed of welding	3–4 ft/hr.

Ideally, the process is carried out with the weld arranged in the true vertical position, but a certain degree of deviation from the vertical can be accommodated, depending on circumstances. The permissible maximum has not been determined but welds

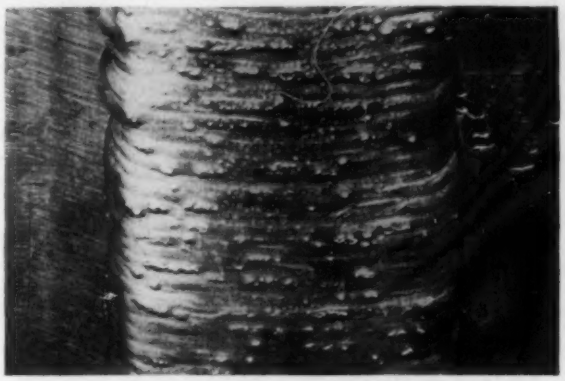
have been made successfully in positions 30° from the vertical both laterally and transversely. Production of such welds requires certain modifications to the machine, such as tilting it so that the rack is parallel to the direction of the weld.

There is no difficulty in making satisfactory circumferential welds if the workpiece can be rotated. For such welds, the shoes must be of about the same curvature as the plate, and the inside shoe must be supported separately from the outside one. It also is necessary to exercise some ingenuity in the manipulation of the wire, particularly in finishing off. It is, in fact, possible to make a complete circumferential weld with this process by chipping out the start to a chamfer while welding is in progress, and by finishing with the use of a water-cooled copper shoe specially shaped to bring the weld proud of the surface at the finish. A similar device, and similar manipulation of the reciprocating motion, is required in picking up after a stop in the middle of a run.

One important potential application of the Rockweld electro-slag machine is in the welding of thick plates of low-alloy steels. The composite nature of the electrode wire enables weld metals for such steels to be developed easily and quickly, and the very nature of the process eliminates the possibility of martensitic cracking at the side of the weld. Moreover, the low build-up of stresses in the weld itself reduces the possibility of weld-metal cracking which can occur with such steels.

Effect of Welding Variables

The aim in electro-slag welding is to melt the minimum amount of parent metal compatible with obtaining sound fusion at the front and back surfaces of the weld. Parent metals vary considerably in quality and since their composition is seldom as acceptable for weld metal as the metal deposited from the electrode, there is an advantage in ensuring that as little as possible is melted into the weld. From a practical viewpoint, to achieve satisfactory fusion at the front and back surfaces of the weld, a certain minimum amount of parent metal must be melted at these points, and it follows that to maintain satisfactory fusion and at the same time keep the proportion of parent metal in the weld to a minimum, the weld should be parallel in section. An important reason for the oscillation of the electrode is now clear. Heat is produced approximately radially around an electrode and thus a stationary electrode, placed at the centre of the gap, will melt a weld pool roughly circular in shape. This causes an unnecessarily large proportion of parent plate to be melted into the weld. Oscillation of the electrode distributes the heat more evenly and it helps to produce a weld of parallel cross-section and so avoids excessive melting. But to achieve a perfectly parallel section it is necessary to control carefully the amplitude of the oscillation. It has been found that there is a slight asymmetry between the back and front of the weld, and to compensate for this the amplitude is also made asymmetrical but in the opposite direction. The achievement of a parallel cross-section is also assisted by arranging for the electrode to pause for a predetermined period at the end of each oscillation.



6—*Surface of electro-slag weld in 3 in. thick boiler plate* ×½

With very thick plates, although even distribution of heat could be obtained by a single oscillating electrode, there is the danger of the slag and metal temperatures dropping between oscillations. The use of two or more electrodes not only combats this but also gives correspondingly higher rates of welding.

By using all these refinements, it is possible to produce satisfactory welds with very little melting of the parent metal, but conditions are then critical and considerable skill and experience are required to avoid intermittent lack of penetration. By permitting rather more than this minimum melting, the process becomes less critical so that, although welds can be produced with as little as 25% dilution (*i.e.* the weld metal comprises 25% melted parent metal) it is more usual to work at dilutions of 35–45%. A typical weld surface with good fusion and edge blend is shown in Fig. 6.

The welding variables that influence the degree of dilution are:

(i) Width of gap between the edges
(ii) Welding voltage
(iii) Welding current
(iv) Slag depth
(v) Speed of the oscillating motion
(vi) Length of electrode protruding beyond the nozzle.

Gap width affects dilution in that there is a minimum gap below which no penetration is achieved, and above which the dilution is almost proportional to the gap width. The reason for this appears to be that, as the gap is increased in width, the convection currents in the molten slag pool are directed in a way that washes away the sides of the gap. Also, with a wider gap the rate of climb is slower and thus the rate of energy input per inch, say, is greater.

The biggest single factor influencing dilution is the welding voltage. Dilution appears to increase almost parabolically with increase in voltage. This is no doubt due primarily to the increase in energy dissipation resulting from increased voltage. The wire burn-off rate is proportional to current and almost independent of voltage, so that increase in voltage at constant current does not increase the rate of welding, but does increase the rate of energy input and thus the amount of side-wall penetration. Higher voltage also gives a more turbulent slag pool, thus increasing the washing effect on the side walls.

The effect of welding current is interesting in that dilution increases with current up to a certain point and then decreases. The reason for this appears to be that, at low currents, increase in current will obviously give more penetration since it produces a higher concentration of energy and a more turbulent slag bath. However, increase in current also causes increase in the pressure on the liquid metal pool and a deepening of the depression in this pool. At high currents there is no doubt that the tip of the electrode is buried deep in this depression in the pool, and there is, in fact, a layer of liquid metal between the side walls and the heat source, which prevents the melting heat impinging on these walls.

An increase in slag depth reduces the dilution, for it causes ineffective dissipation of heat well in front of the point of welding, and thus reduces the concentration of energy there. Among other things this has the effect of reducing the temperature of the slag.

The linear speed of oscillation also has an effect on dilution in that the higher the speed, the less is the side-wall fusion. This is because at higher speeds of traverse, a smaller proportion of the heat liberated is utilized in melting metal as opposed to that required to heat the slag locally. In other words, there is a shorter interval between the commencement of melting and the electrode passing on than there is with slow speeds of traverse. A similar effect can be noted in metal-arc welding; using a wide and fast weave the depth of penetration is less than when a slower weave is used.

Increase in the free length of electrode, other things being equal, reduces the degree of dilution. Here the effect is indirect in two separate ways, in that the greater the free length of electrode, the greater is the wire burn-off rate (since the I^2R factor in the wire is increased) and, because of the voltage drop across the free length of the wire, the voltage drop across the slag is lower. The former factor means that the rate of welding for a given current is increased, and the rate of heat input per inch of weld is thus reduced, whilst, because of the latter, the energy dissipation in the slag is less. Both, therefore, contribute in giving reduction in side wall fusion as the free length of electrode increases.

Speed of Welding

The electro-slag process not only permits weld metal to be deposited at very high currents in the vertical position, but a special feature of the process is that utilization of the electrical energy is very efficient. Normal Class 2 rutile electrodes deposit between 15 and 20 g of weld metal per minute for each 100 amp of current used. With the heavily coated iron-powder electrodes this figure may be as high as 25 g. With the electro-slag process, the figure is 50 g and more. This high efficiency of the electro-slag process can only be due to a combination of very low radiation losses and to the fact that the taper at the melting end of the electrode gives a very much larger area in contact with the heat source than does the flat end in arc-welding processes. It should be noted also that the voltage in the electro-slag process is higher than the normal arc voltage in arc-welding processes.

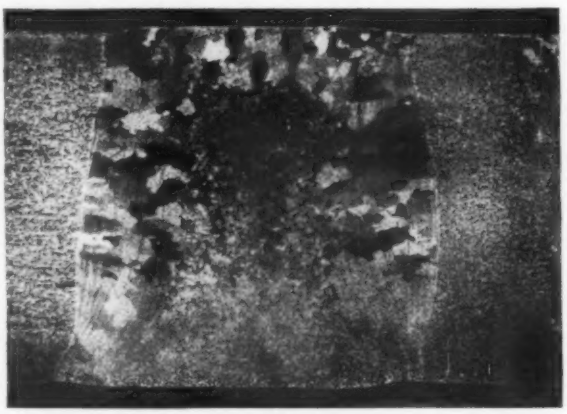
A deposition rate of 50 g/min. per 100 amp of current used, means that the speed of welding is of the order 3–4 ft/hr on plate 2–3 in. thick. The speed of welding is not very much different on thicker plate, since somewhat higher currents are used, and on very thick plate there are two or more electrodes.

Properties

Two main factors influence the properties of electro-slag welds; the proportion of parent metal that is melted and forms part of the finished weld, and the effect of the very large weld pool on the rate of cooling.

Inevitably, in electro-slag welding, the proportion of parent metal that enters the finished weld is very high compared with other processes used for the same thickness of plate. As already mentioned, the dilution is seldom below 25% and a more typical figure is 35%. This amount of dilution never occurs in, for instance, metal-arc welding, except possibly in thin plate or with root runs.

It is clear that with such large dilutions the chemical and mechanical properties of the weld are very much dependent on the quality of the parent metal, and it seems fairly certain that adjustments will have to be made in both procedure and type of electrode wire to cope with differences between parent metals.



7—Cross-section of electro-slag weld in 2 in. thick mild steel showing the large grain size ×½

8—Vertical section of weld shown in Fig. 7, showing more clearly the columnar nature of the grains ×½

The joints illustrated in Figs. 7 and 8 show that the large weld pool and relatively slow solidification can have the effect of giving a weld structure showing large columnar grains. This affects the mechanical properties of the weld, particularly impact values, but unlike a single-run submerged-arc weld, these columnar grains do not meet in a line but merge until they become parallel. The oscillation of the electrode helps to break up the structure but even under the most favourable conditions, the grain size is larger than with other forms of welding.

The slow cooling and the presence of large grains gave, in the original electro-slag process, welds that had very poor impact properties in the as-welded and in the stress-relieved conditions. Good impact properties were restored only by subjecting the whole structure to a normalizing treatment. This is expensive and involves considerable technical difficulties, particularly when the component is very large. With the Rockweld version of the process, the composite wire gives weld metal with quite good impact properties, even in the as-welded condition. The following figures were obtained on weld metal from 2 in. thick material made at 500 amp, with $\frac{1}{8}$ in. wire at a voltage of 42. The vertical speed of welding was 40 in./hr and the gap, before welding, was $1\frac{1}{4}$ in. Tests were made in the as-welded condition:

Tensile strength, tons/sq.in.	34·0	34·75
Elong. on $4\sqrt{A}$%,	30	30
Red. in Area, %	64	66

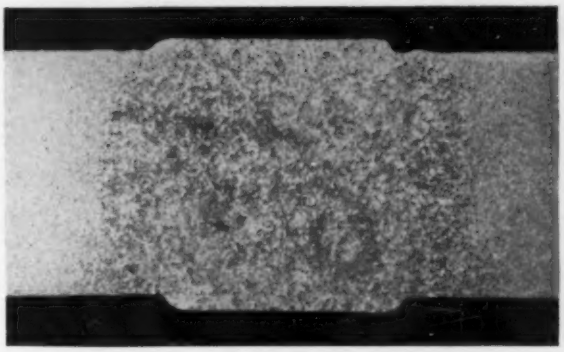
Impact values on transverse specimens with the notch parallel to weld and facing weld surface

Temp., °C.	*Position of Notch*	*V-notch Charpy*, ft/lb.	% *Fibrous*
+20	Back	42	50
	Centre	46	50
	Front	50	50
0	Back	28	30
	Centre	50	60
	Front	32	30
−20	Back	15	5
	Centre	44	20
	Front	14	5
−40	Back	6	0
	Centre	20	10
	Front	10	5

Chemical Composition, %

	No. 1 Plate	*No. 2 Plate*	*Weld*
C	0·22	0·15	0·12
Si	0·013	0·022	0·23
S	0·028	0·019	0·025
P	0·010	Less than 0·005	0·016
Mn	0·69	0·54	1·45

With average quality boiler plate it is thus possible, by correct choice of electrode wire and welding conditions, to obtain satisfactory mechanical properties. In this particular instance, the tensile strength is perhaps a little high, but it can be very easily regulated by control of the manganese content. It is necessary, of course, with this process to aim at a rather higher alloy content to achieve the required strength than with metal-arc welding, where the rate of cooling is so very much faster.[2]



9—*Cross-section of weld made in different plate under different conditions, showing much finer grain size* ×$\frac{3}{4}$

The use of composite wire is still at the development stage and there is a very strong possibility that impact values may be further improved; this may not be merely a question of reducing the grain size. Figure 9 shows an electro-slag weld with considerably finer grain size than that shown in Fig. 7, yet the properties were not markedly superior.

A very interesting feature of electro-slag welds is the magnitude and distribution of the residual stresses left by welding. Preliminary investigation has shown that the maximum value of residual stress is of the order of half the yield stress (as compared with full yield stress for normal arc welds) and that it is tensile in the centre (*i.e.* in the middle half of the thickness) and compressive at the surface. A little consideration suggests a reason for these two facts. The speed of progression in welding is so slow that there must inevitably be a certain amount of spontaneous stress-relief annealing, and as the centre of the weld is the last to solidity and cool there will be triaxial tensile stresses in the centre of the weld thickness.

Since the weld is of the low-hydrogen variety there is no possibility of the hydrogen cracking that can occur in metal-arc welding of alloy steels. Moreover, the rate of cooling is so slow that the possibility of martensite formation at the side of the weld, even with quite highly alloyed steels, does not exist. On the other hand, it has been noted that with some steels, not necessarily of the alloy type, there can be a hardening at the side of electro-slag welds because the very slow rate of cooling discloses any tendency towards precipitation hardening in these steels. This is a phenomena that has occurred in certain notch-ductile steels for which rather special deoxidizing treatments are used at the melting stage. It is not entirely understood at the moment and is receiving further attention.

Site Welding of Large Diameter Studs

AT THE VELINDRE COLD MILL

By R. W. Taylor, A.M.I.E.E., *and A. G. Senior*, M.SC., A.M.I.C.E., A.M.I.STRUCT.E.

The welding of steel studs for the attachment of rails on elevated crane gantries raised several interesting problems. The paper describes the fatigue tests carried out to determine the most suitable form of stud, and the conditions under which the work was carried out. A d.c. power source was obtained from batteries, and special equipment was constructed for prewarming the girders and for machining the studs after welding. The control methods adopted for ensuring maintenance of the required quality are also described.

THE construction of the Velindre Cold Mill for the Steel Company of Wales Ltd. raised several interesting problems associated with the welding and testing of steel studs on elevated crane gantries under normal site conditions, and the techniques which were successfully developed at the time enabled a high degree of reliability to be achieved. In all, some 22,000 $\frac{7}{8}$–$\frac{3}{4}$ in. dia. studs and 4,000 $\frac{3}{4}$ in. dia. studs were welded using, as the only external power source, a normal 230 V, 30 amp. supply. These techniques have subsequently been applied to other work and the same degree of reliability has been demonstrated.

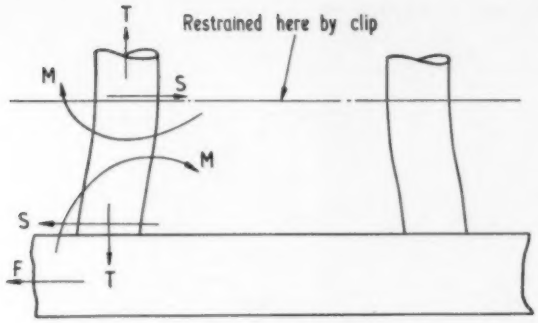
The studs were required to fix spring clips to the top flanges of the crane girders, as a means of securing the crane track, the arrangement being shown in Fig. 1. They were selected from a group of alternatives, which included the manual arc welding of studs, the manual arc welding of bolt heads, and the fillet welding of forged or pressed steel members with studs integrally attached, after studies had shown them likely to be the quickest, cheapest, and most convenient solution subject to meeting the strict requirements detailed.

Design Considerations

The cranes in the five operational bays at Velindre were all intended to be used for production purposes and to be in constant use for up to 24 hr a day for a seven day week, thus making track maintenance very difficult. This high-duty operation, involving frequent crane movements, rendered fatigue an important design consideration for both the gantry girder and the rail fastenings. The gantry girders were of all-welded **I** beam construction fully continuous over their supporting columns, and were of mild steel to BS.15, having a maximum design flange stress of 9 tons/sq. in. under two crane conditions with a 25% impact allowance. The range of axial stress in the top flange from a single crane was expected to be 6 tons/sq. in. under normal working conditions, being wholly tensile over the columns and mainly compressive at mid-span. While the interaction of two or more cranes could produce, under certain conditions, higher stresses, this was not expected very often and was therefore of secondary importance for fatigue considerations.

1—*Welded studs securing the crane rail track*

Manuscript received 17th April 1959.
Mr. Taylor is with Crompton Parkinson (Stud Welding) Ltd., and Mr. Senior is with W. S. Atkins and Partners. 490



2—*Loading conditions on studs*

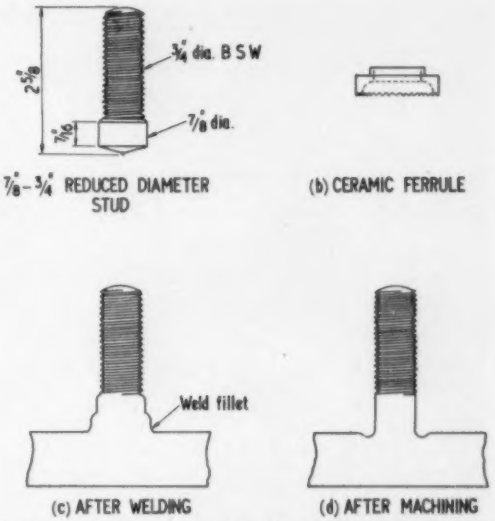
The studs were required to be loaded axially to a constant stress of 10 tons/sq. in. and to resist shear and bending stresses arising from any slip which might take place between the spring clip and the girder flange. Under these conditions of bending, shear, and direct stress, the maximum combined stress would occur at the fillet weld and at the thread root beneath the nut. These conditions are illustrated in Fig. 2. Two criteria of failure by fatigue were considered: transverse fatigue of the girder flange from stress concentrations associated with the stud welding; and the fatigue of the stud through its shank, resulting in loss of clamping. Of these two effects the former was undoubtedly the more important. In the absence of any test data fatigue tests were planned before the final decision was made to stud weld.

Fatigue Tests

Previous work by Koenigsberger and Martin* on the fatigue properties of studs loaded under alternating axial load had shown that studs with cold-rolled threads are capable of withstanding higher stresses under repeated loads than studs with machined threads. The former were therefore specified for this work. The following *ad hoc* tests were carried out in the Fatigue Laboratory of the British Welding Research Association at Abington.

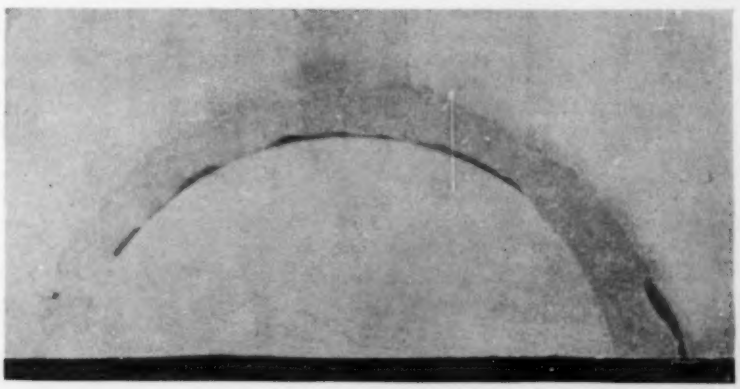
The first group of tests were conducted on a welded model girder, on to the top flange of which $\frac{3}{4}$ in. dia.

*F. Koenigsberger and Z. G. Martin: *Trans. Inst. Welding*, 1953, vol. 16, p. 39.

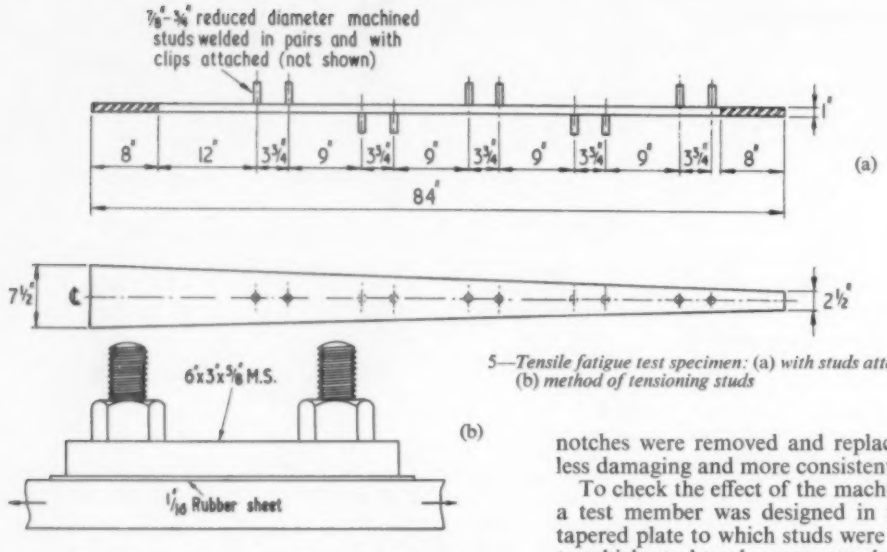


4—*Reduced diameter stud, cutting tool and welded stud before and after machining*

fully-threaded studs had been welded. Clips were attached to the pairs of studs and tightened to reproduce precisely the conditions on the gantry girders, and the test beam was pulsated in a constant-strain testing machine as a simply supported beam loaded at mid-point. Under these conditions the axial stress in the flange varied from zero at the supports to a maximum at mid-span. Failures were expected to occur first at mid-span and then progressively along the beam to the position where the stress corresponded with the 2×10^6 cycles fatigue endurance limit. The first failures did occur at these studs at mid-span after 313,000 load reversals. Examination showed that they originated from circumferential notches positioned at the outer edges of the weld pool beneath the fillets and resembling 'under-cut'. These notches are attributed to arc-blow. A second form of notch was also present in some studs examined, and these took the form of an extension of the vertical surface of the stud into the fillet metal and in certain extreme cases into the fusion zone below the surface of the parent plate. Both notches are shown in Fig. 3. This lack of fusion between the fillet metal and the stud shank can be reduced by carefully



3—*Sectional plan below plate surface showing circumferential notches* ×3½



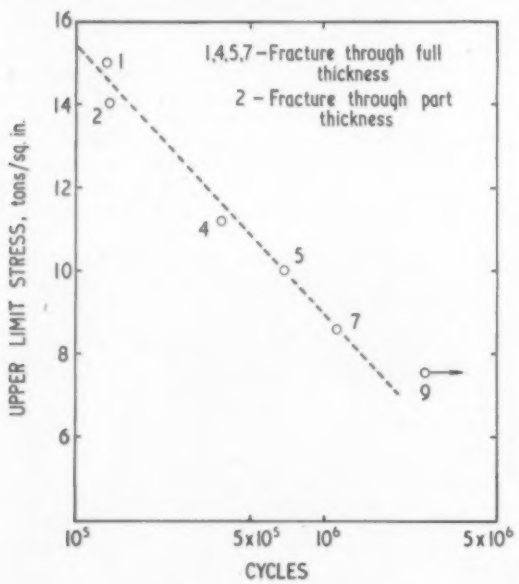
5—Tensile fatigue test specimen: (a) *with studs attached;* (b) *method of tensioning studs*

controlling the rate of power input and the depth of return of the stud into the molten weld pool. These two types of notch were not necessarily present in all studs and were orientated at random. Their effect on fatigue life would be greatest when they are positioned transverse to the direction of longitudinal stress.

To safeguard against these stress concentrations, an enlarged base stud was devised. After welding, this base and the whole weld fillet were machined with a hollow-end milling cutter to leave a groove of known radius round the base of the stud. A $\frac{7}{8}$–$\frac{3}{4}$ in. reduced diameter stud and ceramic ferrule are shown in Fig. 4 together with a welded stud before and after machining. The groove left in the plate ensured that unknown notches were removed and replaced by a potentially less damaging and more consistent notch.

To check the effect of the machined stud in fatigue, a test member was designed in the form of a long tapered plate to which studs were welded in pairs and to which steel packs were attached to reproduce the load conditions (Fig. 5). The plate was subjected to pulsating tensile loads in a Losenhausen constant-load fatigue testing machine to produce a stress range in tension across the plate of 7 tons/sq. in. at the wide end and increasing to 15 tons/sq. in. at the narrow end. After each successive piece of plate failed in fatigue the specimen was shortened and the test was resumed. In all cases fatigue failure started from the base of the machined groove. Results are plotted in Fig. 6. The fatigue endurance limit of 7 tons/sq. in. which was achieved was considered to be adequate for Velindre.

Subsequent tests, undertaken to give a direct comparison between unmachined studs without the previously mentioned defects and the reduced diameter machined studs, show broadly that the machined groove does not reduce the fatigue endurance of an unmachined stud in which neither of the notches that have been described are present.



6—Fatigue test results

Site Conditions

When stud welding commenced in June 1955, only part of the shop was roofed and sheeted, the remainder being exposed to the weather (Fig. 7). The initial stud welding was to be carried out with the rail in position on the girder; in the latter stages the rail was lifted into position after welding. Access for stud welding on the gantries from the walkways was excellent, but much of the floor and machine foundations had not been completed and it was anticipated that some difficulty might be experienced in moving a power source around the shop close enough to the point of welding, which was at a height of 25–40 ft above floor level, to avoid excessive lengths of cable. It was not possible to work progressively from end to end of each bay in turn, as at times it was necessary to switch work from one bay to another to suit the erection programme.

Power Supply

Probably the most vital requirement to achieve absolutely consistent semi-automatic stud welding is

7—General view looking down typical shop

an adequate and uniform power supply. The duration of arc heating is so short that it is usual to preset weld times by trial on sample plates, and it is impossible to adjust welding times and currents to compensate for momentary fluctuations in supply voltage during the short period of welding. The preliminary site survey showed that there existed two heavy three-phase 400 V, a.c. cables entering the two ends of the shop direct from a new sub-station. The ultimate intention was to link the cables to form a ring main. However, the heavy intermittently loaded contractors' plant already connected to these cables would have given voltage fluctuations of such a magnitude as to make substantial differences in the heat inputs of successive stud welds unavoidable. Some other means of providing a power supply was thus necessary.

Several alternative arrangements were considered, including the provision of a trailing 6·6 kV cable direct from the sub-station to supply a 6·6 kV, 440 V step-down transformer. It would have been necessary with this arrangement to move the transformer around the site to supply either a large over-compounded multi-operator welding motor generator, such as is used in the Admiralty dockyards, or possibly two transformer rectifiers connected in parallel. The cost, complication, weight, and danger associated with these arrangements were considerable and it was decided to study the feasibility of secondary lead-acid batteries as a source of d.c. welding power. Subsequent tests proved that a suitable battery power source could be made up which, with appropriate charging arrangements, would give an adequate and consistent power output. This arrangement would also be lighter, safer, and substantially cheaper in initial outlay than any other alternative method. It was decided, therefore, that such a power source should be made up and a battery was built which comprised four 24 V, 480 amp-hr traction batteries connected in series, together with automatic charging equipment designed to replace the energy given out by the battery after each stud weld, with an allowance for battery efficiency. This ensured that consecutive stud welds would be made under identical conditions of power input. The automatic charger was supplied at 230 V from the shop mains through 250 ft of cable, and comprised two 20 amp selenium rectifiers arranged in parallel and controlled by relays in such a way that during stud welding the battery was disconnected from the charger but after completion of each weld the charger replaced the energy used and prevented further welding until this had been done. The batteries and automatic charging plant were mounted together on a 3-ton short chassis truck which proved to be sufficiently manoeuverable to cover the shops.

Stud Welding Equipment

Standard stud welding equipment was used, to which two very minor modifications were made. To ease the duty both on the main contactor and on the batteries, imposed by the short circuit at the end of each weld cycle, a special contactor unit was incorporated in the circuit. This opened just before the main welding contactor and inserted a resistance in the main welding lead. A small neon lamp was provided on the welding hand tool to indicate to the operator when the batteries have been fully recharged.

A total of some 150 ft of 0·3 sq. in. cross-sectional area welding cable was used between the battery power source and the controller, to which the hand tool was connected by 25 ft of cable. This gave a reasonable radius of movement without the need for moving the truck frequently. Twin welding (earth) return circuits were employed, connections being made to the base of the two vertical stanchions below and on either side of the welding position. Normal positive earth polarity was used.

Preparation

The actual stud positions were marked out in groups of four, using a template that was moved along chalk

lines positioned on the girder flange by theodolite. The distance between groups of studs ranged from 15 to 30 in. The place for the stud was marked by a centre punch to locate the cone end of the stud before welding. Mill scale and rust were removed from the surface with a portable grinding tool without obliterating the centre punch marks.

The apparatus used for prewarming the girder flange is shown in Fig. 8. It comprised four 1 kW electric cooker-type heating elements mounted on a frame to straddle the rail, and connected with the shop supply through 200 ft of cable. It was found possible to raise the temperature of the $1\frac{1}{2}$ in. thick girder flange by 15°C. per minute. This heater was used throughout the job irrespective of the ambient temperature.

Stud Welding and Machining

This proceeded in a normal manner using $\frac{7}{8}$–$\frac{3}{4}$ in. reduced diameter studs and standard $\frac{7}{8}$ in. ferrules (Figs. 9 and 10). The standard foot and ferrule holder of the tool were cleaned after each weld to avoid the possibility of spatter from the previous weld impairing its function. Welding speeds achieved after the first few days averaged approximately 230 studs per eight-hour day, rising to a peak of 325 studs per day when site conditions permitted. The 'gang' consisted of two operators and a mate. For machining the studs a portable pneumatic air drill was used, but this was subsequently changed to a portable electric drill possessing a more suitable torque characteristic; this was mounted in a rig designed to run on wheels along the girder flange (Fig. 11). The rig was provided with clamps to fix it to the crane rail at any position and was equipped with a pillar and swinging arm on which the drill was securely mounted. After various trials, nine-tooth cutters made from high-speed tool steel were used. The average rate of stud machining with this equipment was 325 studs per day and the average life of a cutter before sharpening was 400 studs.

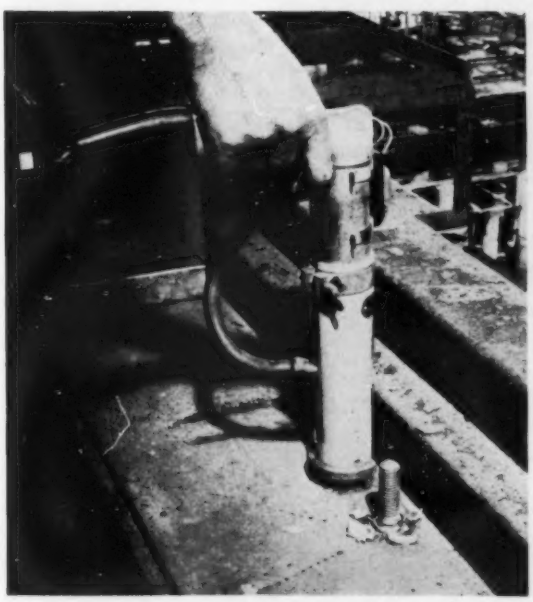
Quality Control

Detailed emphasis was given to the quality control that was necessary to ensure that high standards of welding would be maintained. At the request of the Consultants, the effect of plate temperature was examined by welding a series of studs to plate at different temperatures down to freezing point. It was found that at 32°F. some cracking was present in the fusion zone but that at a temperature of 40–45°F. satisfactory studs could be welded. It was required therefore to arrange for the girder flange to be warmed

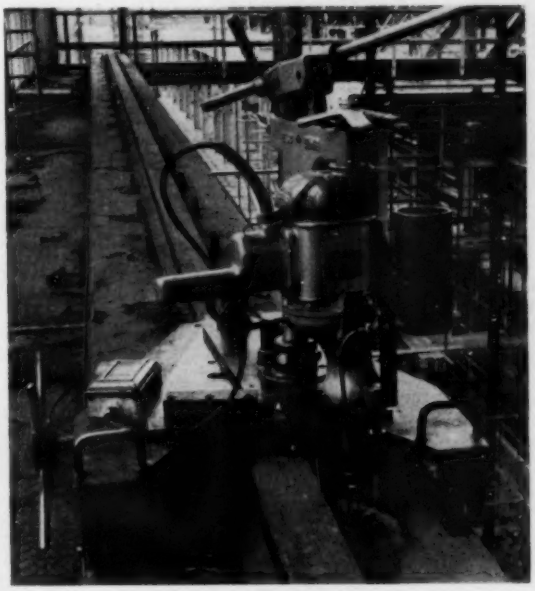
8—Prewarming heaters in position

before stud welding when the atmospheric temperature was below 35°F. The apparatus for achieving this has already been described.

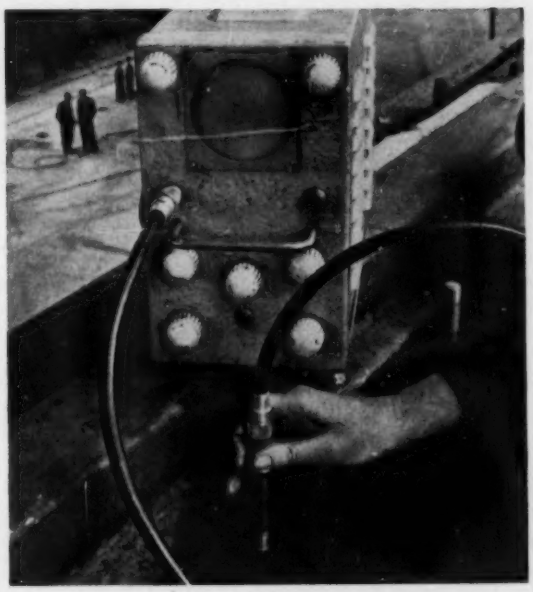
9—*Stud welding in progress*



10—*Stud welding in progress*



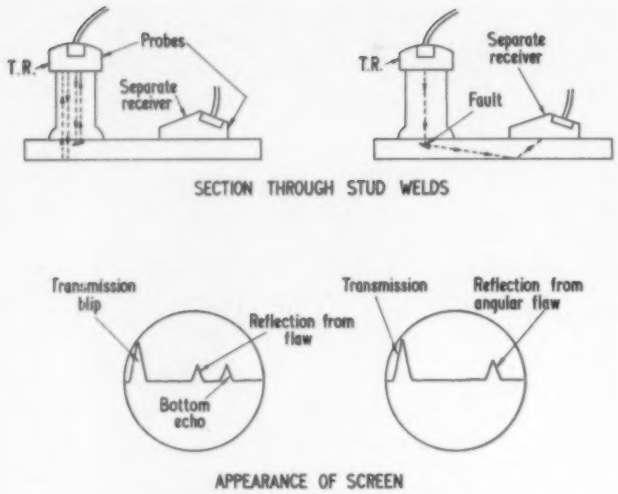
11—*Stud machining rig*



12—*Principles of the ultrasonic methods of testing*

Quality control was achieved by a series of physical, mechanical, and ultrasonic tests. As an immediate check on quality, the finished height of the stud above the plate surface was measured with a stepped gauge and any stud falling outside the allowable tolerance of $+0-\frac{1}{8}$ in. was subjected to further critical examination. All studs were examined in this way.

Two methods of ultrasonic examination were developed. In the first of these a transmitter/receiver probe placed on top of the stud was used to detect the



13—*Ultrasonic examination of a stud using a single transmitter/receiver probe*

presence of any porosity or lack of fusion in the weld zone (Fig. 12). In addition, an angle receiver probe, placed on the surface of the plate and moved circumferentially around the base of the stud, was used to detect any vertical or inclined defects. This second technique required a transmitter probe on top of the stud and used the underface of the flange as a reflecting surface. These methods are illustrated in Fig. 13. The transmission frequency for this work was $2\frac{1}{2}$ Mc/sec, and under site conditions an operator of average competence could readily detect cracks or inclusions having a maximum dimension not greater than $\frac{1}{16}$ in. Sample studs for mechanical tests were required to be taken every day at the rate of one for each hundred studs fixed, and at any time during the day's work at the discretion of the Engineers. These samples were welded on to small test plates and were subjected to tensile and proof loads and ultrasonic examination followed by destructive mechanical tests in either tension or bending.

A proportion of all studs welded were tested *in situ* by loading in tension to 80% of the guaranteed minimum yield stress, using a calibrated torque spanner and a reaction collar. Any stud so tested that showed signs of yielding, indicated by jamming of the nut or by extension of the stud, was rejected. It was required that all defective studs were to be replaced at the contractor's expense.

Throughout the whole of the work, during which 26,000 studs were welded, only five were found to be defective and were replaced. These studs were removed by carefully cutting them away with a suitable tool and dressing off the flange surface by grinding before rewelding. In no case was it necessary to gouge the surface before rewelding. Limited works production commenced in the summer of 1956, and since then no defects in or associated with the studs have been detected.

Following completion of the rail fixing at Velindre the equipment was moved to the Abbey Works of The Steel Company of Wales at Port Talbot, where it has since been in regular use for a similar purpose on extensions and rerailing projects. To the present time a total of some 150,000 $\frac{3}{4}$ and $\frac{7}{8}$ in. dia. studs for rail fixing had been welded with the technique described.

Acknowledgments

The authors wish to thank The Steel Company of Wales Limited for permission to publish certain photographs and data in this paper. Thanks are also due to W. S. Atkins and Partners, the Consulting Engineers responsible for this work, and to Crompton Parkinson (Stud Welding) Ltd., who supplied equipment and studs and were Contractors for the work.

WELDING INSPECTION LAMPS

An additional inspection lamp, without the need for extra trailing wires and suitable connection points, can be a valuable tool for a welder operating in already congested conditions.

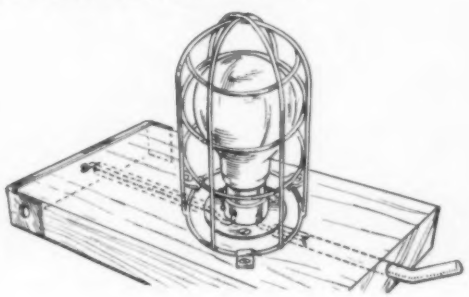
A device for this purpose was designed by the late Mr. Gordon Musted, and was illustrated, somewhat obscurely, in the paper he wrote for presentation to the IIW Assembly at Opatija. It is thought that some readers might be interested to have more detailed particulars.

The construction of the lamp is shown in the accompanying diagram. A suitable piece of scrap hardwood is drilled to take wires from each end, and is fitted in the centre with a lampholder and stout cage.

At one end is fitted a metal shoe, which is connected to one terminal of the lampholder. At the other end is fixed a short piece of rod (say an electrode core), which is bent to suit the shape and type of electrode holder in use. This is then connected to the other terminal of the lampholder.

The operation of the lamp is extremely simple. It is gripped at the rod end in an electrode holder, and the circuit is completed through the welding power source by earthing the shoe by resting it on the workpiece.

Perhaps a warning should be given that arcing of the shoe to the workpiece should be carefully avoided, especially with high-tensile steels, for this can lead to local hard spots forming likely sources of fatigue failure of the component in service.



Autumn Meeting 1958

Part 2

The Autumn Meeting of the Institute of Welding was held in London from Wednesday to Friday, 5th to 7th November 1958, commencing with the Annual Dinner at the Park Lane Hotel on the evening of 5th November.

There were four technical sessions held at the offices of the Institute on the Thursday and Friday, for the presentation and discussion of papers. The Chairman at the first session was the President, Mr. J. Strong. The Vice-President, Mr. E. Seymour-Semper, took the chair at the second session. The Chairman at the third session was Professor G. Wesley Austin, and at the fourth Dr. E. G. West.

The first part of the discussion on the papers was published in the June 1959 issue of the Journal (pp. 248–254). It is now concluded in this issue.

Carbon Dioxide Welding and Production of Automobile Chassis Side Members* *By S. Astley*

Mr. C. R. Thompson (John Thompson Motor Pressings Ltd.): In making the particular sidemember described by Mr. Astley we had to decide whether to use the conventional method of carbon-arc welding or to branch out into a process that at that date offered many difficulties combined with interesting benefits if it were successful. Many people considered that the CO_2 process was not possible, but we certainly intended to try it. The subsequent success of the machine that was built is evidence of the author's ingenuity in developing it.

This is proof of the view (supported by the history of submerged-arc welding) that if a firm is prepared to do the development work that is obviously necessary and to make a number of mistakes, it is very likely that success will be achieved in the end. I consider that the growth of CO_2 welding has only just begun, and that its possibilities are as yet not appreciated.

Mr. A. H. Mulder (Philips Electrical Ltd.): I agree with Mr. Thompson's remarks and it is for the equipment manufacturers to adapt this process to particular needs.

In a recent visit to the two main motor car factories in Germany I noticed that CO_2 welding heads were used to a very great extent for the fabrication of component parts. The heads are moveable so that they run round circumferential welds and the components are automatically fed into position by electronic control. During a sixteen-hour day one machine produces as many as two thousand items, or even more. This is possible only with the CO_2 process, which can provide speeds two or three times faster than the normal method. We have found that the best applications are in thicknesses from 14 s.w.g. to perhaps $\frac{3}{8}$ in. Some manufacturers who are employing the process in this country are doing development work on the heavier gauges.

The process is also very suitable for many other applications, because it is so simple. It does not require cleaning of the weld or additional work once the seam is finished; for instance, for galvanizing components. In addition, the penetration can be controlled to such an extent that fusion into a plate welded from one side only can be controlled to 90% or more.

Mr. I. C. Fitch: The inert-gas shielded metal-arc process has been the subject of intensive study by both equipment manufacturers and steelmakers for several years, but in the welding of thicker gauges there are still a number of quite tricky problems unsolved. In the motor car industry the process has a particular combination of qualities which suits it extremely well.

Some calculations I have made suggest that the specific fusion rate of the electrode in Mr. Astley's machine was rather on the high side, but I was unable to allow for the extension of the electrode from the nozzle. Could we have this dimension?

Mr. D. B. Tait (Quasi-Arc Ltd.): Mr. Astley's work has shown that the bare-wire/CO_2 process can give high production speeds on a specific application. Deposition rates for this method of welding are usually quoted at a maximum of 25 lb/hr, and this does not compare with processes shielded either by gas and flux or flux alone, where deposition rates of 35–90 lb/hr can be obtained. It would thus seem unlikely that the bare-wire/CO_2 process will displace the other processes on conventional work.

It is interesting to note that in France bare wire, without a gas shield, is widely used on work in the automobile industry.

Mr. E. Seymour-Semper (Chairman): The manufacturer with initiative is always glad to tackle new problems, because in that way he learns, and his special machine today may become his standard machine tomorrow. So I do not think any enlightened manufacturer—and surely in the welding industry we are all fairly enlightened—would avoid tackling a project to help a customer.

On the other hand, of course, development is proceeding so fast today that a manufacturer may not be able to undertake such development work in addition to current production. The ideal is complete co-operation and understanding between the manufacturer and the user.

Mr. C. L. Railton (Tube Investments Ltd.): We have found that the CO_2 welding process without sufficient shielding gas gives a most unsatisfactory deposit and certainly not a good weld.

Has the author experienced any trouble from the ring of spatter detaching itself from the end of the contact tube and being carried down on the wire into the weld? We have found that this causes batches of badly shaped welds. Perhaps he would also mention how he has overcome other difficulties in regard to spatter falling onto guide and feed rolls.

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* *Brit. Welding J.*, 1958, vol. 5, p. 389.

I disagree with Mr. Tait's contention that CO_2 welding is a slow process. For the making of small fillet welds it is probably the fastest process that is at present available.

Mr. **L. M. Gourd** (British Oxygen Gases Ltd.): In the course of the normal development work on the inert-gas shielded-arc processes at the British Oxygen Research and Development Laboratories, a programme of work on CO_2-shielded welding was undertaken, and although the results were published in 1956 there appeared to be very little response from the industry at that time.

Basically, the equipment required for CO_2-shielded welding is no different from that required for argon-shielded welding, and the one equipment will serve both purposes.

Mr. Astley's attention has been drawn to the extension of the electrode from the contact tube. We have done a considerable amount of work on I^2R heating and there appears to be no doubt that horizontal-vertical welding can be improved by preheating the electrode, using the I^2R effect. It would be interesting to know whether Mr. Astley has considered this aspect.

The copper coating of the wire stops rusting, but it also confers certain other advantages, as the author found. In particular, the contact resistance between the wire and the contact tube is reduced. It is not obvious, however, whether this is due to the copper itself or results from a reduction in contamination.

Author's Reply

Mr. **Astley** wrote in reply: The progress we have made with bare wire CO_2 welding has been very considerable on a difficult job, and this is in no small way due to the enterprise of Mr. Thompson and his fellow directors in expending their capital and in encouraging me during the early days of design and developments. I am sure that the results cannot do other than encourage both manufacturers and users of welding equipment to turn their attention to further development of the process.

Mr. Mulder is correct in stating that gas-shielded bare-wire welding is extensively used on the Continent and in America by the motor-car industry on automatic and semi-automatic welding machines, and I am sure that its possibilities will be quickly recognized in the U.K.; we shall certainly apply it further in our factories.

The reply to Mr. Fitch's enquiry is that the extension of the electrode from the contact tube is about $\frac{3}{8}$ in., the gas shield nozzle being $\frac{5}{8}$ in. from the workpiece, and the contact tube is $\frac{1}{4}$ in. inside the gas nozzle.

The deposition rate of a process is not always the prime factor to be considered, and as Mr. Tait remarked, this is a special application; *i.e.*, two standing fillets in the 3 o'clock position on 14 s.w.g. material, which we could not produce satisfactorily with any other process.

I have no experience of welding with bare wire and no gas shield in recent years, but I do know that if the gas supply fails or is inadequate when using the CO_2 process the result is a very porous weld that would not be accepted by our customer.

I agree with Mr. Seymour-Semper that co-operation between users and manufacturers of equipment is the ideal condition for mutual progress, and in fact it was so in this case, but my only criticism is that we could not obtain equipment in Britian suitable for this job *when we wanted it*, which because of circumstances beyond our control was at very short notice indeed, but I am sure this position will be remedied.

We have not experienced much trouble from spatter, and very little adheres to the component, possibly because the two welding heads are in the 3 o'clock position, and what little spatter there is falls downward. Some of this adheres to the lower feed roller from which it is continuously removed by two high-speed steel cutting tools. We also protect some parts of the machine with anti-spatter paint. The ring of spatter inside the gas nozzle is removed after about every 150 ft of weld, but this will obviously vary with different jobs.

Welding speeds are often limited by variation in component fit-up, and it sometimes pays to sacrifice some quantity to gain in quality and to avoid corrective action later.

Most manufacturers of welding equipment have done research and development work on gas-shielded arc welding, but very few precision coiled wire electrodes of suitable composition were, or indeed still are, available. This is probably the biggest single factor retarding the use of gas-shielded arc welding of mild steel today, together with the high price of such wire electrodes as are available. There is also much divergence of opinion on what is the most suitable power source, especially for use with the thinner electrodes at around 150 amp.

I did not seriously consider the I^2R effect mentioned by Mr. Gourd, but I did establish by experiment the most suitable conditions for the equipment and electrode that we had to use, and consistently good results were obtained. Copper-coated wire helps considerably to combat the major cause of trouble in CO_2 welding with thin electrodes (*i.e.*, electrode feed stoppage while welding) by:

(a) Preventing rust build-up in storage
(b) Assisting slip between wire and contact tube
(c) Giving better electrical contact, resulting in a better arc.

These factors combined permit the deposition of lighter and more consistent welds of better appearance than is possible with uncoated wire, so giving a longer weld for a given length of electrode.

Metal Arc Welding of Aluminium Bronze Alloys*

By M. K. Williams and W. I. Pumphrey

Mr. **J. G. Young** (British Welding Research Association) There is some confusion about whether there are any problems in the welding of aluminium bronzes, and this has led to the recent formation of a new British Welding Research Association committee to investigate the factors influencing cracking, embrittlement, and corrosion resistance in aluminium bronze welds.

Interest is, of course, largely centred on the inert-gas shielded welding process, and in particular the inert-gas metal-arc process, with its obvious advantages in freedom from flux problems and higher productivity. It is not anticipated that the metallurgical problems will be very different from those encountered in metal arc welding, although it would perhaps be unwise to prejudge the issue now that a comprehensive investigation is under way.

The hot cracking tests by Marsh, mentioned by the author indicate that a simultaneous reduction of nickel from 5·3 to 0·2% and an increase of manganese from 0·45 to 5·09% reduces the tendency to hot cracking. Are these the only results available and do they represent deposit or electrode analyses?

What conclusion are we intended to draw from the results on Alloy 2 which has a much lower iron content and does not seem to fit in with the other two.

I should like to hear Dr. Pumphrey's views on the exact mechanism of intergranular penetration in the bronze welding of ferrous materials with high internal stress. The paragraph on this subject seems to suggest that cracks are formed and filled with bronze. May not the mechanism be more akin to stress corrosion where grain boundaries that are preferentially attacked form stress raisers, resulting in the root of a notch, and thus permitting the opening of a crack leading to deeper penetration and further attack?

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* *Brit. Welding J.*, 1958. vol. 5, p. 445,

I would agree with Dr. Pumphrey that for welding alpha aluminium bronze the answer may well be the use of filler alloys giving duplex weld metal, although corrosion aspects have yet to be investigated. Good quality duplex wire for inert-gas metal-arc welding is now available.

Author's Reply

Dr. W. I. Pumphrey (in reply): The corrosion resistance of aluminium-bronze weld metal has given rise to some recent speculation. One of the main attributes of the aluminium-bronze alloys, of course, is their excellent resistance to corrosion, and it has been suggested that to secure the maximum resistance an alloy, whether single or duplex, should be welded with a metal of the same composition and structure as the parent material. Mr. Williams and I have carried out a limited number of corrosion tests on α alloys welded with both α and duplex weld metal and on duplex alloys welded with these same weld metals. Under a variety of corrosive conditions there is little or no extra corrosion attack due to a difference in the composition and structure of the weld metal and plate material with copper-aluminium alloys of low-manganese content. We have found, however, that if the high-manganese aluminium bronzes are welded with low-manganese weld metal of either single or duplex structure the corrosion resistance of the weld is poor, and good corrosion resistance can be secured only by welding the high-manganese alloys with weld metal of the same composition. More work is required, however, on the effect of differences in the composition and constitution of the weld metal and parent material on the resistance to corrosion of aluminium-bronze weldments, although we are more reassured on this score than we were when we discussed the matter with Mr. Young some time ago.

I am sorry that we quoted so few results on the hot-cracking tests carried out by Marsh, but these results were all that were available to us at the time of writing our paper. The compositions quoted in our paper relate to weld metal. We agree with Mr. Young that the quoted result for the alloy containing 1·9% iron is somewhat anomalous, although we have suspected for some time that nickel has a greater influence than either manganese or iron in affecting hot cracking.

The factors involved in the wetting and penetration of a solid metal by a liquid metal are somewhat complex and for this reason we did not dwell at any length on the intergranular penetration of ferrous materials by aluminium bronze weld metal.

A great deal of work has been done recently, particularly in the atomic energy industries, on the penetration of liquid into solid metal.

In any consideration of this subject, it is necessary to give attention to a variety of matters such as the temperature of the base metal, structure, degree of internal stress, grain size and grain orientation and the nature of any precipitates or impurities at the grain boundaries.

In the facing of mild steel with aluminium bronze weld metal all these factors can apply. There is almost invariably some stress on the actual weld and there are certainly impurities at and around the grain boundaries, as well as a range of grain sizes in the solid metal. I am not certain which of these factors contributes most of the actual penetration of the ferrous metal by the liquid bronze weld metal but I suspect that under welding conditions the stress on the parent material and the condition of the grain boundaries are the most important considerations, and I feel that the picture presented by Mr. Young is substantially correct. The instances of cracking combined with penetration of bronze weld metal into steel parent metal which have come to our attention have been those in which a weld deposit has been made on a transverse section of a steel plate where the orientation of the grains in the steel has been at right angles to the weld metal. This undoubtedly has some bearing on the cracking of the steel since any impurities or inclusions would be elongated and orientated in a direction perpendicular to the layer of weld metal, thus presenting a ready-made notch effect as suggested by Mr. Young. The successful welding of ferrous parent material which results from the deposition of an intermediate layer of mild steel weld metal between the parent plate and the aluminium bronze weld metal is probably explicable, though over-simplified on this basis. With the proper precautions, however, the facing of mild steel with aluminium-bronze weld metal is a perfectly practicable proposition, and gives good results for wear-resisting and corrosion-resisting applications.

Welding of Some Creep Resisting Steels*

By J. F. Mercer

Mr. I. C. Fitch: It can be argued that although the welds in a steam main may be a small proportion of the whole, if the weld metal has creep properties different from that of the pipe, it will stretch at a different rate, and this could set up differential stresses at the junction between the weld metal and the pipe which might have an adverse effect on the service life of the joint. I should like to have Mr. Mercer's comments on this problem.

We have done a fair amount of work on the molybdenum vanadium steels and we have so far found that the best sort of heat treatment for this type of weld metal is to normalize at about 970°C. followed by 3–4 hr temper at 690°C. It is a fairly complicated treatment, and I should like to have Mr. Mercer's views on the optimum heat treatment of 2¼% Cr–1% Mo weld metals.

Many creep tests have been done on the more highly alloyed metals used for jet engines and suchlike, because the service life of those metals is low and the operating time required from the creep-testing machines to get a result is not so very great, but the service life of the creep-resisting steels used with turbine construction is about ten years, and it is very difficult to get reliable creep data without taking a very long time for the tests. It is by no means unusual for one machine to be occupied for twelve months in testing one specimen. Considering the number of variables involved in this problem there are not sufficient machines in this country to do all the work that is necessary Perhaps the B.W.R.A. should be persuaded to be interested in this problem, not so much to do the work themselves but to organize and co-ordinate the work that is being done elsewhere so as to use the available machines to the best advantage.

Dr. C. L. M. Cottrell (Bristol Aerojet Ltd.): Something has been said, both in the paper and in the discussion, on the relative merits of creep strength and creep ductility, but is it inevitable that a high strength should always be accompanied by a very low ductility?

Creep failure seems to be initiated at the grain boundaries by a sort of tearing apart of the metal at this point, perhaps associated with non-metallic inclusions. Could the ductility of the weld metal be improved by reducing the level of the impurities which segregate to the grain boundaries, since as the strength of the steel increases, thus putting up the strength of the grain, this tends to throw more stress on the boundary. It may be that by reducing the level of impurities one might be able to attain a reasonably ductile weld combined with the maximum creep strength of the parent material.

I should like to know whether Mr. Mercer has any views on this subject.

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* *Brit. Welding J.*, 1958, vol. 5, p. 472.

The Chairman (**Professor G. Wesley Austin**): In speaking of the increasing importance of creep-resistant materials, increases of pressures and temperatures have been mentioned. I assume that an increase in pressure raises difficulties because of the need to increase the thickness of the pipe and of the weld.

Mr. **M. C. T. Bystram** (Murex Welding Processes Ltd.): In recent years, cracking in the heat-affected zone of heavy austenitic piping has been reported in conditions prevalent in steam generating plant. It is partially associated with the post-heat treatment given to the joints, and has not been encountered in materials of lesser thickness (below 1 in.) and with the lower stresses and temperatures of service in the past.

Professor Austin: When aluminium bronze electrodes are used to weld steels of the same composition, or two dissimilar steels, I assume that the modulus of the weld metal would be about two-thirds that of the steel. It might be that such a weld would have many advantages, because of its low modulus. If, for example, a given strain is to be imposed on a length of piping, it could be absorbed in the weld metal instead of the loads increasing in the main part of the structure.

Dr. **W. I. Pumphrey** (Murex Welding Processes Ltd.): There are difficulties in forming the joint between dissimilar metals, but this is a feature that should be examined. It should be realized though that the different expansion coefficients would probably have more effect on the quality of the weld.

Professor Austin: Perhaps Mr. Mercer would comment on the relative importance of the boundary and the matrix, and how each affects the behaviour of the weld metal.

It is a great handicap that there are so few techniques available for the study of grain boundaries. One is the experimental method of damping capacity and the other is the electron optical method, but neither are very helpful. Even with films of intergranular penetration it is only when the layer is fairly thick that it can be seen with the optical microscope.

Mr. Thorneycroft spoke earlier of the advantageous influence of manganese in Inconel alloy rod, and this reminded me of Dr. Cottrell's work on sulphur. Could the effect of the manganese be to buffer or hold the sulphur and so prevent the formation, in these rather sensitive highly-alloyed metals, intergranular, or in this case interdendritic, films of sulphur? All these factors show the importance of developing further techniques for investigating grain boundaries, for there is already a good deal of information on the matrix.

Mr. **P. G. Heath** (Metropolitan-Vickers Electrical Co. Ltd.): Could anyone comment on the effect of high-frequency vibration in creep tests? Would it accelerate creep?

Professor Austin: For low-melting-point metals, fatigue superimposed on creep has been found advantageous in some conditions of loading. I do not know whether much work has been done on high-melting-point metals, but I think with tin and lead it may be a question of relaxation or recrystallization.

Mr. J. F. Mercer: There appears to be some difference of opinion about the creep properties of weld metal as compared to those of the parent plate. I consider that the most important factor is that the weld metal should be capable of retaining its ductility under service conditions, but I would agree with Mr. Fitch that the creep strength of the weld metal should be high enough to avoid setting up differential stresses at the junction.

With regard to the optimum heat-treatment of 2¼% Cr–1% Mo weld metal Mr. Fitch will appreciate that we must be guided by the steel maker. We normally recommend stress relief at 690°C., a temperature which develops the optimum properties of the base material. Alternative treatments have not been investigated to any extent and we hope to do some work on this in the near future. It should be appreciated however, that the weldment must be treated as a whole and heat-treatment of the weld metal must not be studied as a separate entity.

I would endorse Mr. Fitch's remarks regarding creep testing capacity for weld metal. In view of the extent to which welding is used in the fabrication of modern steam raising plant the amount of machine capacity devoted to the study of weld metal is woefully inadequate.

Dr. Cottrell's questions are extremely important when one considers the creep resistance of weld metal, but we do not know the answers. I do not feel that high strength must inevitably be accompanied by poor creep ductility and I am fairly certain that it is possible to produce several different weld metals each equal to the parent plate in creep strength and creep rate, but varying widely in creep ductility as measured by stress rupture rests. Investigation on these lines will take many years and at the end of that period we may be in a better position to answer Dr. Cottrell.

The increased thickness of the pipe used in installations operating at higher pressures, referred to by Professor Austin can introduce some difficulty in welding, and if the thickness of the pipe were increased to 3 in. or more special electrodes might have to be introduced. Efficient inspection of the welds by X-ray methods can also prove difficult if the pipe is very thick.

With regard to the relative importance of the boundary and the matrix on the creep strength of the weld metal, I am afraid that once again my reply must be that there is very little known about this point. The question regarding the effect of precipitation on creep strength raises an interesting issue. In a recent paper presented to the Iron and Steel Institute Glen* correlates creep rate with percentage strain. One of the points which he makes is that changes occur in the curve prepared in this manner as the test proceeds and he attributes these changes to the formation of precipitates. In some instances alloys which have a reasonable creep rate in the early stages of the test suddenly accelerate after a few thousand hours, and this increase in creep rate is attributed to the cessation of precipitation; in short, everything that can precipitate has come down and the alloy is metallurgically 'bankrupt' if such a term may be used. Where weld metal is concerned this phenomena is rather disturbing because if the beneficial precipitates are predominantly carbides there is very little carbon present in weld metal as compared with the base material. On the other hand, weld metal contains relatively large quantities of nitrogen and this may compensate for the lack of carbon. This subject is one which will bear considerable investigation and should prove an interesting field for future work.

My reply to Mr. Heath is that it is unlikely that ultrasonics can have a pronounced effect on creep in the range of temperatures where the associated amplitude of vibration does not add significantly to the stresses. This will apply even more to the austenitic welds, which tend to damp the ultrasonic vibrations more than the austenitic base metal.

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* J. GLEN: *J. Iron Steel Inst.*, 1958, vol. 190, pp. 30–39.

Some Guidance on Welding Dissimilar Alloy Steels*

By M. C. T. Bystram

Mr. **D. R. Thorneycroft** (Mond Nickel Co. Ltd.): Mr. Bystram's excellent survey of dissimilar alloy combinations has covered more ground than that suggested by the title. Thus, a selection of flux-coated electrodes is given for the metal-arc welding of heat-resistant and corrosion-resistant nickel-base alloys in a variety of combinations, and conditions for welding are described. The more prevalent combinations are those involving nickel and nickel-copper alloys with mild steel, and the nickel-chromium alloys with heat-resisting or mild steels. Although it is customary to select the electrodes listed by Mr. Bystram, nevertheless there is obvious merit in having available a single electrode which will suit most, or all, combinations. One such electrode is an Inconel-type, with the approximate composition shown in Table 1.

We have found the electrode to be particularly suitable for making crack-free welds in a variety of joints involving heat- and creep-resistant alloys, and Table 2 shows combinations of plate butt-welded under conditions of moderate to severe restraint. Figure *A* compares the weld ductility of butt-joints between Nimonic *DS* (2% Si) and mild steel made with the Inconel-type electrode and an 80/20 Ni-Cr electrode.

Table 1

Nominal Composition of Inco Rod 'A' Deposits

C	0·15% (max.)	Nb	1·0–3·0%
Si	0·75% (max.)	Fe	6·0–12·0%
Mn	1·0–3·5%	Cr	13·0–17·0%
Mo	0·5–2·0%	Ni	Substantially balance

Table 2

Plate Materials welded with Inco Rod 'A' Electrode
(Metal-arc welding)

Nimonic 80A	to	H.R. Crown Max heat-resisting steel (cast material)
Nimonic 80A	to	25 Cr/20 Ni heat-resisting steel
Nimonic 80A	to	18 Cr/10 Ni/1 Nb heat-resisting steel
Inconel	to	Mild steel
Nimonic *DS*	to	Mild steel
18Cr/8Ni/Ti stainless steel	to	Mild steel

The paper is concerned primarily with the selection of flux-coated electrodes, but the possibility of entrapped slag in metal-arc welds constitutes a hazard with welded joints intended for service at elevated temperatures. The use of fluxless welding processes, such as the inert-gas shielded process, avoids this problem. We have applied argon-shielded consumable electrode welding to some combinations of dissimilar materials involving high nickel-chromium alloys. With this process also, the choice of welding wire presents a problem, since we find that an 80/20 Ni-Cr deposit is not sufficiently crack resistant. However, an Inconel-type wire is available containing 2½% Mn and 3% Ti, that produces, for example, sound fillet and butt welds between plates of Nimonic 75 and 18/8 Cr-Ni stainless steel in substantial thicknesses. The exact role of manganese and titanium in relation to crack resistance is not wholly understood at present.

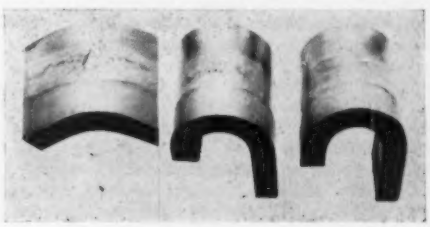
Table 3

Sheet Materials Welded with 80/20 Ni-Cr Filler Wire
(Argon-arc welding)

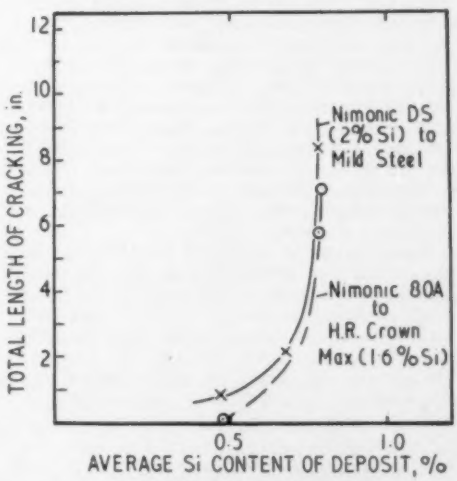
18 Cr/8 Ni stainless steel to	Inconel Nimonic 75 Nimonic 80A Nimonic 90
28 Cr/20 Ni heat-resisting steel to	Inconel Nimonic 75 Nimonic 80A Nimonic 90
Mild steel to	Inconel Nimonic 75 Nimonic 80A Nimonic 90

Welding conditions are usually less onerous when welding sheet material, and the selection of a suitable filler material is somewhat simplified. Table 3 lists combinations of sheet materials up to ⅛ in. thick welded with 80/20 Ni-Cr filler wire by the argon-arc process.

Finally, I would refer to the author's remarks on the problem of hot cracking in weld deposits contaminated with silicon derived from high nickel alloys. The silicon content of most of the wrought nickel alloys rarely exceeds ½% and it is improbable that more than ¼% Si enters the



A—Bend ductility of various butt welds



B—Results of tee cracking tests

* *Brit. Welding J.*, 1958 vol. 5, p. 475.

weld pool from this source. On the other hand, the heat-resisting alloy, Nimonic *DS*, contains about 2% Si, but this is the only high-silicon wrought alloy of the nickel series which is likely to be encountered in sheet, plate, or tubular form for welding. Naturally the presence of this amount of silicon in the base material produces severe contamination of an adjacent weld deposit. For example, single-run fillet welds between Nimonic *DS* and mild steel made with flux-coated electrodes contain up to 0·8% silicon.

The results of tee cracking tests on joints between Nimonic *DS* and mild steel, and Nimonic 80*A* and a cast stainless steel containing 1·6% Si, presented in Fig. *B*, show the influence of silicon on weld soundness. The weld metals were deposited from either 80/20 Ni-Cr or Inconel-type electrodes by metal-arc welding. The form of the curves would suggest that there is a threshold value of about ½% for the silicon content of the weld deposit if extensive hot cracking is to be avoided. A satisfactory metallurgical solution to the problem remains to be found.

The Chairman (**Professor G. Wesley Austin**): I was very interested in Fig. 1 of Mr. Bystram's paper, which showed the migration of carbon from mild steel through weld metal into a low carbon austenite. Is it possible to hold the carbon with a strong carbide former like vanadium, in the weld metal, so that transfer to the austenite is inhibited?

Author's Reply

Mr. **M. C. T. Bystram** (in reply): There is little I can add to Mr. Thorneycroft's valuable contribution, except to point out that while there is possibly much to be said for the use of the argonarc process in the welding of complex alloys, where the development of special metal-arc electrodes may not be justified, there are sometimes objections to the use of the argonarc process for welding certain of the high-nickel alloys mentioned in Table 3 of Mr. Thorneycroft's contribution. These objections result from the recovery of titanium and aluminium when using Nimonic 80*A* and Nimonic 90 filler wires for the welding of the respective alloys, since these are precipitation hardening and thus become liable to cracking. Mr. Thorneycroft's use of aluminium-free 80/20 Ni-Cr filler wires (Table 3), is very sound even though increased creep strength is sacrificed in favour of crack-free welds, which of course implies returning to a weld composition obtainable by the metal-arc process.

The phenomenon of carbon migration from ferritic base metal to the austenitic weld metal during service in the medium range of temperatures is associated with the lower solubility of carbon in the ferrite as compared with austenite, and to the presence of carbide formers like chromium, molybdenum, etc., in the austenitic welds. It results in the formation of a decarburized (weaker) zone in the ferrite material and a stiffer band rich in precipitated carbides on the peripheries of the austenitic weld. The resulting local sharp drop in mechanical properties, aggravated by the difference in co-efficients of expansion near the junction, may lead to thermal fatigue effects and ultimate failure along the junction.

This tendency can be reduced by the use of low-alloy base metal containing carbide formers like Cr, Mo, V, Ti, etc. to fix the carbon in the ferritic material.

The use of welds, for example, in the form of a buffer-layer, with co-efficients of expansion closer to the ferritic material and having lower solubility for carbon (*e.g.*, some Ni alloys), would also be advantageous, provided that this would satisfy also the other demands encountered in service.

Erratum

In the presentation of the paper I pointed out a mistake in Table II on page 479, which designated the electrode of 25 Cr/20Ni type as class *G* instead of class *H*: in consequence all class *G* electrodes in the table should read class *H*.

Manual 'Open Air' Welding of Reactive Metals*

By J. C. Borland and W. G. Hull

Mr. **K. A. Peel** (Short Brothers & Harland Ltd.): The title of this paper is somewhat misleading, for the work covered is primarily gas flow, which is equally as important in automatic as well as manual welding. The subject, welding of titanium, involves a great deal more than gas flow at the torch. There is no mention of the effect of argon backing to the weld jig design.

Many companies are using the colour change characteristic of titanium as an inspection criterion. How reliable is this when it is known that even an apparently 'clear' weld may be contaminated? Does the use of the word 'clear' mean a 'bright' weld, if so of what colour? since it is possible to produce both dull and bright welds in a range of colours. In some cases removal of discoloration, regarded as surface contamination only, by vapour blasting is permitted. Is this wise when there is apparently no means of assessing whether contamination is skin deep or throughout the weld?

The nozzle described is no doubt satisfactory in the laboratory, but so as to reduce the number of cables, gas and water pipes the already harassed operator has to deal with, I should like to know if there is any fixed relationship between the three outlets. This would suggest a design embodying a single feed with metering orifices to each section.

Mr. **F. Copleston** (British Oxygen Gases Ltd.): There is very much more to manual 'open air' welding of titanium than the problem of gas coverage from the torch. Jigging is a major factor since it must provide alignment of the component, chilling of the weld area, gas protection to all heat-affected areas, and also may contribute by forming a baffle which will trap the gas over the weld area.

Experiments on various single-flow shield designs proved that a standard annular orifice of adequate diameter was satisfactory where the jigging was of correct design. Experience with a shield, similar to the one described in the paper, proved that torch manipulation is difficult, access to weld is limited, and vision of the weld pool restricted.

Bearing in mind some of the limitations in the welding of titanium, I would make a plea for careful design of any component which may require repair in service. Gas coverage to the weld and other heat-affected areas may prove to be impossible, resulting in a need for a major replacement operation.

Authors' Replies

Messrs. **J. C. Borland** and **W. G. Hull**: One object of the investigation was to establish the various relationships between argon flow rate, nozzle dimensions, nozzle-work distance, and the welding speed which were important in obtaining good shielding. From this knowledge a multiflow nozzle was designed which was sufficiently compact to be used manually. As with other materials jigging is an important factor and may well be used to provide extra gas coverage when conventional round nozzles are used. Large round nozzles of ¾-in. dia. have a low critical velocity and in some instances they may allow contamination of the molten pool to occur. This can be more dangerous than surface contamination.

We have not previously heard the word 'clear' used to describe the surface appearance of titanium welds. Such a

* *Brit. Welding. J*, 1958, vol. 5, p. 427.

vague term in this connection should be avoided. Surface coloration is a useful guide but not an absolute indication of weld quality. When contamination is suspected, hardness measurements should be made. With the best techniques, the hardness of c.p. titanium weld deposits made in a single pass should not exceed by more than 20 points D.P.N. the hardness of the metal immediately adjacent to the fuzed zone[1]. Since with increase in hardness, the ductility decreases, the deposit hardness of c.p. titanium should not exceed 250 D.P.N. otherwise the weld will be severely embrittled[2]. When possible, the efficiency of the shielding system used should be checked by hardness and bend tests.

We agree wholeheartedly with Mr. Copleston's plea for careful design of components. Too little attention has been paid to this aspect in the past.

In answer to Mr. Peel's question we can say that there is no rigid relationship between the argon flows to the three compartments. Good welds have been made with a number of different flow combinations. We would stress however that if a porous diffuser is not used for the trailing shield, there appears to be a critical flow relationship which must be used to achieve optimum results.

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1. C. A. TERRY and E. A. TAYLOR: *Weld Metal Fab.*, 1958, Vol. 26, pp. 198–205.
2. J. C. BORLAND: Confidential Report C4/1/58, September 1958, British Welding Research Association.

Current and Pressure Wave Shapes used in Resistance Welding* *By W. A. Knipe*

Some Aspects of Cross Wire Welding of Aluminium Alloys† *By G. H. Batten*

Mr. **E. V. Beatson** (Joseph Lucas Ltd.): I should like to congratulate Mr. Batten on his photocell device for indicating exactly at what instant in such a short time cycle of about 1/25 sec. the particular trouble occurred.

We have had experience in applying a similar type of slope control, not to aluminium but to the resistance brazing of copper wires to plated brass. The current pattern was of the same general shape as Mr. Batten's, and as first set up the operation was also extremely critical. Accurate instrumenta.. .., in this case of current and voltage, was needed to reveal the weakness and develop the best cycle. But the results when obtained were well worth while and quite capable of being consistently maintained. For the past three years, around 60,000 joints a week have been produced on a completely automatic machine with no trouble. Perhaps manufacturers of slope control equipment would bear in mind that many such applications appear critical if the correct conditions are not established in the first place. To do this it is necessary to be able to measure and adjust independently the time for the 'slope in' for welding and for the 'slope out'. At present these variables have to be calculated from the rate of slope and the overall time.

Mr. Knipe in his Fig. 6 indicates that with the three phase frequency converter system, the 'slope out' can be prolonged. Can this slope out be varied over a reasonably wide range, and also can the slope in and slope out be varied while maintaining more than one pulse of a normal shape in between?

Mr. **N. T. Burgess** (Aluminium Development Association): There are so many snags connected with the cross wire welding of aluminium that it is good to see that many initial deterrents have been satisfactorily overcome, thus leaving the way clear for others to develop the procedure to a finer degree.

The welds that Mr. Batten has obtained seem extremely good, much better than one would expect from a study of the basic difficulties involved. With aluminium, applied heat is very quickly drawn into the body of the wire, thus making it difficult to localise heat at the interface. The pressure then applied cannot be effective, because it is cushioned by the collapse of the surrounding material. The aluminium is softened and it does not provide sufficient backing. In steel, the metal behind the interface does not collapse in this way, and satisfactory welds can result.

Ideally, therefore, one requires an aluminium alloy that, while retaining its beneficial properties of high durability and low weight, has electrical and thermal properties similar to steel. I believe special copper alloys (Everdur and Tungum) do possess such characteristics.

I am fairly certain that no aluminium alloy will ever be found that fully meets these requirements, but I wonder whether Mr. Batten's excellent work might usefully be extended to cover other aluminium alloys, such as the heat-treatable materials, particularly H9 and H30, which in the fully heat-treated condition would have greater initial strength and would back up the weld more satisfactorily than the aluminium 1¼% manganese alloy used by the author. It is well known that the aluminium-magnesium alloys have an oxide film inherently different from that on pure aluminium. This would explain some of the author's difficulties with this particular type of material.

His Fig. 2*b*, however, shows a very strange effect which seems to be a sandwich of oxide film with unaffected parent metal in the middle. It would be particularly interesting if Mr. Batten could publish the metallurgical micro-sections of these particular welds.

I note from page 419 that better results are obtained by using a wire that is given a special surface treatment. I presume that this is the conventional zincate treatment that is widely applied to ordinary filler wire for the inert-gas metal-arc process. It is extremely clean, and one wonders whether further developments in the treatment of the wire to remove the surface film and so on might not give better results than Mr. Batten has obtained.

A study is currently being made of the mechanics and electrical aspects of stud welding, and it is becoming increasingly apparent that not only the amount of pressure but the time at which pressure is exerted is extremely important in obtaining a sound weld. Would it not be possible to collate the study of the two processes in this respect?

Finally, I would agree with Mr. Batten's closing paragraphs, particularly those concerning the present disadvantages of cross wire spot welding. As the author says, however, any new method would be cheaper and easier than methods currently available, which invariably mean a fusion-welded joint. It would be extremely valuable to know exactly what capacity of machine is required to make the welds referred to in the paper, and from there to judge whether this would in fact be a costly operation for the user.

Many companies at present operating spot welding equipment are aware that aluminium always requires machines of much higher rating and have installed them where necessary. New and costly equipment may not, therefore, always be required.

Mr. **C. L. Railton** (Tube Investments Ltd.): Mr. Batten has emphasized the need to use a dual pressure cycle and to control this accurately. Would he consider that the spot welding machine with a double-acting air piston (which he used for his work) is the ideal type of machine or would a diaphragm operated machine with reduced friction and inertia be more suitable?

* *Brit. Welding J.*, 1958, vol. 5, p. 417.
† *Ibid.*, p. 341.

I would also welcome his views on the consistency of the time delay inherent in the relays.

Authors' Replies

Mr. **Batten** wrote in reply: I agree with Mr. Beatson's comment on the desirability of ease of setting of the various controls. In the tests carried out it was necessary to examine the wave shape of the trace on a C.R.O. and to adjust the control panel dials as required.

I would ike to correct a statement in the published paper where I have referred to "specially coated wire". This should refer to wire which has had a special surface treatment.

I agree with Mr. Burgess that further work on surface treatment, in co-operation with the wire suppliers, seems a very promising line for further investigation, particularly as such improved results have already been obtained.

The kVA requirement for welding aluminium alloy wire compares favourably with that required for spot welding, but the point was emphasized because a large number of machines used for the cross-wire welding of steel are small, foot-operated types of low kVA capacity and with simple current and pressure control. The capacity used was of the order of 150 kVA for the thinner wires, and up to 350 kVA for the $\frac{1}{8}$ in. dia. wires on a machine with 36 in. throat depth.

The machine used was designed to enable higher forces and currents to be available than were found necessary for wire up to $\frac{1}{8}$ in. dia. Probably some improvement could be obtained using a diaphragm-operated head, bearing in mind the lower maximum force that needs to be accommodated for this range of sizes. Care must be taken to ensure that the flexible current connection offers minimum restriction to follow up.

The relay that operated the high-speed air valve was of the standard Post Office type with a reasonably constant operating time. As the delay time for the second pressure was initiated at the same time as the weld, the air-valve operation should be consistent. On the tests carried out, variations were not apparent from the results. A more positive way to ensure consistency could be obtained if the air valve switching were done by thyratron.

Mr. **Knipe** wrote in reply: The slope-out can definitely be varied over a reasonable range. It may be any length required, from half a cycle up to say 90 cycles, the only limitation being the design of the particular machine being used. The slope-in and slope-out can certainly be varied whilst maintaining more than one pulse of normal shape between. The time and magnitude of slope-in and slope-out, as well as the welding current time and magnitude, may be varied for each pulse. There is no technical limitation on these variables when designing a control.

I should like to make a point regarding Mr. Railton's remark on pressure and relays. It has been proved without doubt that when welding aluminium, especially alloys for stressed structure for aircraft, the diaphragm and roller bearing or similar antifriction device is essential to consistant welding results.

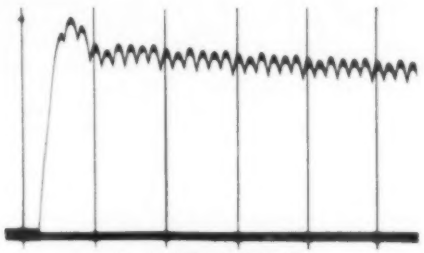
Relays or other mechanisms which may give a variable time should be eliminated and replaced by electronic controls to ensure reliability.

Developments in Power Sources for Inert-gas Tungsten-arc Welding* *By M. Waller*

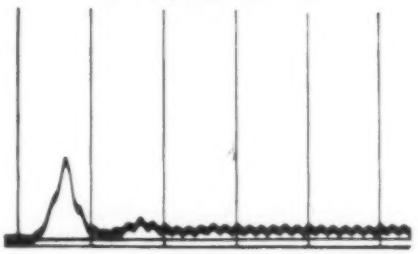
Mr. **J. C. Needham** (Electrical Research Association): The saturable reactor is very suitable for remote control application and for giving substantially stepless variations of output current, but it is a complicated device when transient conditions such as starting or stopping are encountered.

The three usual windings, a.c. input, a control d.c., and the output current winding, interact, and until equilibrium conditions are established there is a transient stage where the current delivered from the power source can be very different from the final output.

Theoretically, a simple d.c. source instantly delivers the given output and in general arc starting is then easy. In practice, the starting current waveform varies considerably with the design of the transductor, and over a period of a few cycles the current may differ appreciably from the equilibrium output level (see Figs. A and B for high and low current settings respectively from a 3-phase transformer rectifier set).

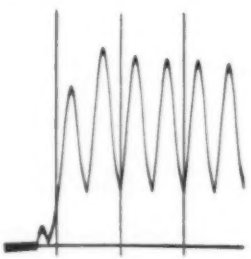


A – high current setting



B – low current setting

A & B – Starting current waveforms for 3-phase transformer rectifier



C – Small loop of current preceding normal output level

Time scale: 1/50 sec timing lines

In this connection the excellent high-speed cine film of tungsten-arc spotwelding clearly showed a billowing bright arc at the start followed by its contraction to a pale, narrow arc, and finally the steady arc with rapid minor fluctuations. These changes correspond to an over- and under-shoot of current such as illustrated by Fig. B with, finally, a 300 c/sec. ripple due to the 3-phase bridge rectifier.

The undershoot at low current settings can be a cause of difficult arc starting, particularly with a manual set up where an operator making an inadvertent movement immediately after the arc had struck might cause it to extinguish in the low current period.

* *Brit. Welding J.*, 1958 vol. 5, p. 407

The same general characteristics apply to other forms of rectifier set. For example, a single-phase bridge rectifier with transductor control did not exhibit a large current overshoot but had a very heavy 50 c/sec ripple in the output current. This led to the possibility, when the arc was started at random with respect to the 50 cycle waveform, of having a small initial loop of current preceding the normal output level (see Fig. C). This would make for difficult starting for, in effect, the cold tungsten electrode sized for, say, 100 amp would be operating initially at as little as 10 amp.

One must also consider much shorter periods of time of the order of 1/1000 sec. With a spark just injected to initiate the arc, the arc has then to be established by power source current. The rate of rise from zero varies considerably with different designs of rectifier set, some of the well-designed ones reaching up to 100 amp in the first 1/1000 sec, *i.e.*, a rate of 100,000 amp/sec.

In other cases, however, and particularly at low current settings, the initial rate of rise may be as low as one amp for the first millisecond. Having as little as an amp at the early stages is generally inadequate, giving difficult starting. This is particularly so if there is appreciable capacitance of upwards of one microfarad, such as a h.f. by-pass condenser, across the welding circuit. This capacitance discharges into the arc immediately on starting, and if undamped this discharge will extinguish the arc instantaneously at the moment of starting. For example, in a typical circuit a 10-microfarad condenser charged to about 100 V on open-circuit will give instantaneously 50–60 amp oscillatory current, positive and negative, and the first negative peak occurs in rather less than 0.1 millisecond after starting. If the main power source were to overcome that oscillatory discharge, to ensure good starting, the current would have to rise by about 1,000 amp in a millisecond, which does not occur. It is therefore very important to have all capacitances damped which could discharge into the arc gap at the moment of starting, and in the above example 3 ohms in series with the capacitor itself would be adequate.

Mr. **B. E. Dorey** (B.W.R.A.): From the wiring diagram of the rectifier set and the text, it would appear that contactor switches are used on both primary and secondary sides of the transformer. I should have thought it possible to use one contactor only, on the primary side, with auxiliary contacts and so reduce the complexity and cost of the equipment.

Concerning the arc initiating circuits in the rectifier plant, would higher arc voltages and longer cable lengths make it necessary to alter the value of the resistance *R*7 to compensate for the increased impedance of the outside circuit? Some situations demand long welding torch leads and the operator should not be expected to have to alter electrical settings.

Furthermore, I have found that thoriated electrodes of the smallest practicable diameter will give the most rapid starting, although such may overheat with prolonged use.

Regarding Mr. Waller's film, it was shown that, when the electrode was hot it was very difficult to restrike the arc when using a straightforward h.f. starting unit. My experience with another type of unit has been exactly the opposite: it is very difficult to establish an arc when the electrode is cold but it will strike instantaneously when it is hot.

Author's Reply

Mr. **M. Waller**: I was very pleased that Mr. Needham was able to elaborate on the characteristics of starting of rectifiers, because he knows a great deal more about this subject than I do.

Referring to his curve where the current rises and then falls to a very low value, we suspect that it can actually fall to zero under certain circumstances with present equipment. We think that may be one of the reasons why we still have not obtained 100% arc starting. We are aware of this and we hope that by improving the design of the power unit itself we can overcome this tendency to undershoot.

Referring to Mr. Dorey's remarks about circuit-breakers it will be appreciated that the primary contactor is not operated normally under load conditions. It is more a safety device in that it is tripped when the fan fails. We prefer to do the switching on the secondary side rather than switch on the primary, as the Americans do. This is mainly because it is kinder to the rectifiers, which do not like switching surges.

Regarding arc starting, if the value of the damping resistance *R*7, in the discharge circuit of the condenser, is somewhere near the critical damping value this will be satisfactory. But if the cables are long there will possibly be a fraction of an ohm extra in the circuit, although we have not found it necessary so far to make adjustments.

I agree that, in general, the smaller point on small thoriated electrodes gives better arc starting.

Only in the past few days have we met the peculiar phenomenon on the high-speed picture with h.f. failing to restrike with a hot electrode, and we agree with Mr. Dorey that it is contrary to normal experience. We have not yet found an explanation.

INTERNATIONAL INSTITUTE OF WELDING

Recommendations for the Choice and Classification of Steels for use in Welded Structures

These recommendations state the guiding principles on which to base the choice and the classification of steels for electric arc welding with covered electrodes of normal penetration. They cover only rolled structural mild steels and carbon-manganese steels.

Factors Affecting the Choice of Steel

DURING 1949, Commission IX of the IIW agreed the following definition of weldability, which was adopted by ISO/TC 44 "Welding" in 1953:

A metallic material is considered to be weldable to a certain degree by a given process and for a given purpose, when a continuous metallic connection can be obtained by welding using a suitable procedure, so that the joints comply with the requirements specified both in regard to their local properties and their influence on the construction of which they form part."

This definition admits a 'degree' of weldability. A logical development of this concept is the idea of classifying steels in groups, which correspond to different degrees of weldability.

The definition then draws attention to the precautions required; these vary according to the 'degree of weldability'. Their object is to prevent:

(i) The occurrence of cracks or fissures (*e.g.* hot cracking)
(ii) The formation of brittle constituents (*e.g.* hardening effects)
(iii) Brittle fracture.

Hot cracking

Hot cracks in weld metal are formed during cooling of the weld. It is believed that they are due to the insufficient ability of segregated regions to accommodate strain. Therefore the degree of constraint of the welded assembly is important. Furthermore, impurities (*e.g.* sulphur) and a high carbon content in the solidifying weld metal have proved to promote hot cracking. As these elements could enter the weld from the molten base material, the limiting carbon and sulphur values given in these recommendations generally refer to the risk of hot cracking in the weld metal. A high sulphur content may also promote the formation of blowholes in the weld metal.

Hardening effects

As a result of the rapid heating during welding and of the thermal conductivity of the metal, the heat-affected zones are subject to a rapid cooling which may produce hard and brittle constituents (even martensite). These hardened zones are situated approximately in the same region as the maximum residual stresses and may be, at the same time, subject to a volume increase due to hardening, initiating supplementary residual stresses. These are particularly dangerous zones in which cracks may occur. This danger can be diminished by low carbon content, by reducing the cooling speed (for instance by preheating) and by using low-hydrogen electrodes.

Brittle fracture

Brittle fractures are generally formed without plastic deformation; these fractures should be considered from the viewpoint of their initiation and of their propagation.

Initiation is governed by different factors; some may arise from welding (*e.g.* weld defects and residual stresses), other factors are the local state of stress (geometry and rigidity of the construction) and the properties of the material at service temperature.

Propagation is governed by the state of stress and by the properties of the steel at service temperature.

For these reasons the properties of the steels as

Document IIW/IIS–22–59 (ex doc. IX–230–58) of Commission IX 'Behaviour of Metals subjected to Welding'. When Commission IX of the International Institute of Welding took up its work in 1949, under the chairmanship of Dr. Geerlings (Netherlands), it was decided that the Commission's programme should include the preparation of recommendations for weldable steels.

A document was published in 1955 regarding the minimum requirements for rolled or forged structural steels to be suitable for electric arc welding.

From 1956 a Sub-Comimssion, under the Chairmanship of Mr. Bonhomme (Belgium), has investigated the possibility of re-drafting this document, and the present document was unanimously recommended for publication by Commission IX in its Vienna annual meeting in 1958. 493

regards brittle fracture have been considered a principal factor in the choice and classification of steels for welded constructions.

Some qualitative suggestions about the possibility of diminishing the danger of brittle fracture, taking into account the characteristics of the construction, are given in the following paragraphs.

It follows that the risk of cracks and fissures occurring, or of the formation of brittle constituents, or of brittle fractures depends on:

(*a*) The properties of the steel as supplied
(*b*) The complexity of design of the structure (geometrical factors, shape, thickness of material, etc.)
(*c*) The nature and level of the stresses, and the service temperatures, to which the welded assembly is exposed
(*d*) The fabrication and welding procedures.

The choice of steel as regards properties (*a*) depends on (*b*), (*c*), and (*d*).

It is therefore evident that the degree of weldability of a steel cannot be defined on the basis of one criterion only.

Effect of properties of steel as supplied

The characteristic properties of a steel are determined by its chemical composition, the metallographic structure, the manufacturing practice, and the thermal or mechanical treatment which it has undergone prior to arc welding. Further, the properties of a steel may be modified locally, to a greater or less extent, by the welding operation itself. Experience has shown, however, that a classification of steels could be made on the basis of a certain number of their properties, and a classification of this type, within the limits of applications defined on p. 531, is given below.

For the choice of a quality of steel, however, the degree of complexity of the structures, the conditions to which they are exposed and the welding conditions, should be considered.

Effect of complexity of structural design

Just as steels can be differentiated according to their resistance to brittle fracture, welded structures may be differentiated according to the complexity of the design, with special reference to those factors which influence the tendency to brittle fracture: *viz.* degree of restraint, stress concentration, etc. Structures may show different degrees of complexity of design according to the magnitude of the following factors: degree of restraint, grouping of welds, rigidity, discontinuities in shape and thickness of material used.

The degree of complexity of the structural design must be taken as a basis for the choice of steel, having special regard to the nature and level of the stresses and the welding procedure.

Effect of stresses and service temperature

The choice of steel must depend on the nature and level of the external stresses which the welded structure must withstand. External stresses may be classified as: static stresses and dynamic stresses, both originating from external loading and/or temperature variations. It is well to bear in mind that, for a given state of stress, the danger of brittle fracture increases as the temperature falls. Special attention should be given to stress concentrations that may arise from the complexity of structural design.

In proportion as stress conditions become more severe, an increasingly high quality of steel should be considered, together with the appropriate welding procedure.

Effect of welding procedure

Apart from the type of steel, the design of the structure, and the nature and level of the stresses, the welding procedure has a considerable influence on the final result. The thermal conditions depend on the method of welding. A low heat input and a high cooling rate favour the development of brittle constituents. A high heat input and a low cooling rate have the opposite effect.

Thermal conditions depend on the thickness of the parts to be welded, the diameter of the electrodes, the intensity of the welding current, the welding sequence and the ambient temperature, especially for steels over 33 tons/sq. in. actual tensile strength. The compatibility of parent metal and filler metal, and hence, the choice of steel, may also be influenced by the welding method. The residual stresses and the risk of crack and fracture formation increase with increasing thickness of the material. Special precautions and/or a higher quality of steel are necessary above certain thicknesses, the limits of which vary with the grade of steel and with the service conditions and, thus, cannot be absolutely fixed. The special welding precautions mentioned above are, *e.g.*, welding with preheating, welding with local or complete postheating for stress-relieving, welding with electrodes having particular properties, welding sequence, etc.

In deciding whether special precautions should be taken, it may be useful to carry out test welds so as to assess the risk of crack formation and/or excessive hardening in the heat-affected zone (see p. 533).

Conclusions

The choice between the different qualities of steel depends not only on the intrinsic properties of the steel, but also, to a great extent, on design, on the nature and level of the stresses to which the structure is exposed, on the welding procedure and on the service temperature.

Limits of Applications

The present recommendations apply to rolled products such as plates, sections, and bars of mild or C–Mn structural steels of grades from 22 to 33 tons/sq. in. (minimum specified tensile strength) used for structures such as bridges, buildings, and the like, ships, rolling stock and locomotives, storage tanks, machine frames.

The present document only gives the recommendations that, in the present state of knowledge of weldability, can reasonably be put forward. It should be understood that these recommendations presuppose that proper precautions are taken to ensure that good welding practice is followed.

The general principles may also apply, in certain circumstances, to other kinds of structures such as pressure vessels, boilers, penstocks, pipe-lines for water, gas, or oil, though, for such structures, the limiting values given in this document may require some adjustments.

Classification of Steels for use in Welded Structures

Criteria for classification

Commission IX believes that the selection of steel should be based upon the properties of the final product.

The main criterion used in classification is the notch-toughness of the material. This criterion is supplemented by recommendations regarding the chemical analysis and homogeneity of the steel.

The recommended level of properties can be controlled, either by acceptance tests on finished products or through agreement between parties on a particular practice for the manufacture of the steel if this practice has been shown to give the desired level of properties.

Although a large number of proposals have been made for different methods of investigating the problem of brittle fracture and for different types of tests, the recommendations given below are based on the V-notch Charpy test, which is widely known and has been extensively used.*

Classification

Four steel qualities are to be considered, namely: A, B, C, and D.

Quality A steels satisfy only moderate conditions and offer a certain safety against the risk of crack and blow-hole formation in the weld.

Quality B steels are intended for use in welded structures or structural parts, not of excessive thickness, subjected to normal loading conditions† and having a normal safety factor in service.

The use of these steels is generally justified for structures or structural parts in which brittle fractures are not to be feared, either on account of the thicknesses sizes, and shapes adopted, or on account of fabrication and/or service conditions.

Quality C and quality D steels (improved notch-tough qualities) are to be used for structures or structural parts, whose design, importance, and/or service conditions necessitate the risk of brittle fracture being taken into account.

These qualities differ from one another in their applicability at different service temperatures or, for the same service temperature, in their notch-toughness.

Quality C steels are to be used where, owing to thicknesses, loading conditions, and the general design of the structure, some resistance to brittle fracture is necessary.

Quality D steels are to be used where, owing to increased thicknesses, loading conditions, and the general design of the structure, a high resistance to brittle fracture is necessary.

Structures are considered to be exposed to the risk of brittle fractures when, on account of their thicknesses, sizes, and structural design, or on account of their fabrication and service conditions, they present a high rigidity and discontinuities which may initiate cracking at service temperatures.

Of course, this classification does not imply that the whole welded structure should be made of the quality required for those parts of the structure which are subjected to the more severe conditions.

For the selection of the steel quality to be used, account should be taken of the points mentioned in the first part of these recommendations.

It is recalled that for any structure, whatever steel quality is used, preheating or a stress-relieving treatment may allow the choice of a steel having a lower quality, for instance C instead of D and B or A instead of C.

Experience has shown that the use of a steel of a lower quality can also be considered for structures that are submitted to a full scale test on the finished structure, adequately duplicating service conditions.

Qualification Tests for Steels

Chemical analysis

Steels with an actual UTS up to 33 tons/sq. in.

If the carbon content of the steel does not exceed 0·22%, special welding precautions will not, in general, be necessary.

If it is between the following limits:

0·22–0·27% for qualities A and B
0·22–0·24% for qualities C and D

special precautions may be necessary, particularly regarding the choice of electrodes.

If these carbon limits are exceeded, special welding precautions will generally be necessary.

The sulphur and phosphorus contents should not exceed the following limits:

	S, %	P, %
Quality A	0·06	0·08
Qualities B and C	0·05	0·06
Quality D	0·05	0·05

Steels with an actual UTS between 33 and 45 tons/sq. in.

If the following limits are exceeded, special welding precautions will, in general, be necessary:

	C, %	Mn, %	Si, %	S, %	P, %
Qualities B and C	0·22	1·50	0·55	0·05	0·06
Quality D	0·22	1·50	0·55	0·05	0·05

This statement is, however, subject to two reservations:

(*a*) In these types of high-tensile steels, the carbon content should never exceed 0·22%

(*b*) Special welding precautions will not be necessary where the limiting value of manganese is increased above 1·5%, provided that C+1/6 Mn is equal to or less than 0·47%‡.

It should be noted that, for practical reasons, the limits for analysis given above refer to ladle analyses.

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* This does not exclude alternative tests, provided that a proper level of requirements is chosen.

The results of Charpy V-notch tests and of U-notch Charpy tests are compared in IIW Report No. IX–116–55 by Mr. Audigé (France): "Notch toughness of hull quality ship steels evaluated by means of keyhole and V-notch Charpy tests." (Brit. Welding J., 1956, vol. 3, page 246–254.)

The Van der Veen test, described in IIW Report No.XII–125–53, may be used in tests on the full thickness of the plate.

Sub-Commission A "Comparison of brittle fracture tests" (Chairman: Mr. W. Barr, United Kingdom) studied the correlation between different types of tests and criteria on a wide range of steels and has issued its report: IIW document No. IX–214–58, which has been recommended for publication.

† "Loading" means "stresses" and covers all the forces which must be resisted by the structure or structural parts, and thus includes residual stresses due to welding.

‡ This formula is only intended to be used for this particular group of C–Mn steels.

However, if a check analysis on finished products is desired, this may be arranged by agreement with the suppliers of the steel.

Homogeneity of the steel

All steels to be welded should be free from laminations (significant lack of metallic continuity in the thickness). Further, steels of qualities B, C, and D should be free from segregations that could be harmful as regards formation of cracks and other weld defects.

Brittle fracture tests

For steels of qualities A and B*, no brittle fracture tests are recommended.

For steels of qualities C and D, a brittle fracture test should be made. This test should be made with Charpy V-notch specimens, taken in the direction of rolling, with the notch perpendicular to the surface of the plate or product.

Steels of quality C and D are characterised by an average V-notch Charpy impact value of at least 20 ft/lb., at a temperature of 0°C. for steel C and −20°C. for steel D.

The number of tests to be made (minimum 3) is a matter for agreement between parties.†

These testing temperatures and energy levels were not selected as having particular significance with respect to service performance; they were selected only to classify steels according to their increasing resistance to brittle fracture.

Special welding tests

In the present state of knowledge, it is difficult to recommend any particular test to reveal the tendency to cracking. Several such tests are available and are described in IIW document No. IX–26–53 by Mr. Granjon, France (see p. 531).

In some cases, it may be desirable to arrange for such tests to establish a suitable welding procedure.

* For a few steels of quality B, and for some applications, it may be useful to consider either notch-toughness requirements less severe than for quality C, or some limits to the nitrogen content.

† Attention is drawn to the sequential method described in IIW Document No. IX–184–57, "Contribution to the study of an acceptance method of testing for weldable steels C and D using the V-notch Charpy test, on the basis of a conventional specimen" by Messrs. H. Herbiet (Belgium) and S. Descovich (Italy), recommended for publication.

PLASTIC DESIGN

Book Review

LYNN S. BEEDLE, "*Plastic Design of Steel Frames*": New York, 1958, John Wiley & Sons; London, Chapman & Hall Ltd., 406 pp. (£5 4*s*. 0*d*.)

Simple plastic theory is a bending theory; it explains the condition and behaviour of a mild steel section stressed in bending beyond the elastic limit. Its application to design assumes an unlimited plastic range within which a section reaches its ultimate resistance to bending with the spread of yield stress over the full cross-sectional area and the development of a plastic hinge. The magnitude of the hinge moment is readily calculable.

The concept of the development of plastic hinges in beams and certain rigid structures gives the clue to the way in which they ultimately fail, that is as hinged mechanisms. The theory thus provides a means of determining the collapse loads of such structures and, conversely, a method by which they can be designed to carry working loads with any desired factor of safety.

As long as it can be ensured that a structure would fail in this way if overloaded, then the plastic method of design is directly appropriate, very simple, and advantageous from the point of view of economy.

The theory can be adjusted to take account of minor influences such as axial stress and shear, but uncertainties and complications unfortunately arise with consideration of instability—the lateral buckling of beams and columns—as a possible cause of premature failure.

These complexities have been for some years the subject of a considerable amount of research both in this country and in the United States. In his book Dr. Beedle admits that "the problem of specifying the critical length of a beam, such that premature lateral buckling will be prevented, has not been completely solved" and "much has to be learned about framed columns, . . . the buckling problem becomes exceedingly complex, . . . a complete solution is not in hand". The present limitations of plastic design are clearly indicated in the last paragraph of the book which says that the outlook for the immediate future would involve application of the principles to "structures in which the columns are designed primarily for bending with relatively low axial force. The two-storey, and in certain cases, the three-storey structure would probably fall within this category. Otherwise for tall multi-storey buildings with diagonal cross-bracing, plastic analysis may be applied to the proportioning of the beams".

Dr. Beedle presents the principles and methods that are the basis of plastic design and shows how they may be used in the solution of practical building frame problems. On the subject of instability he gives guidance, based on the results of his own study and research at Lehigh University, and that of other investigators, as to how its effects might be taken into account to ensure the stability of sections selected for a plastically designed structure. The first half of the book deals with fundamental concepts and methods of analysis and design, and includes useful chapters on connections and deflections. The second half is concerned specifically with design and contains a chapter on "Design Guides" as a special feature providing summarized references to all the general provisions, analysis procedures, design procedures and recommendations presented in the book. It concludes with six worked examples of single, two-span, and three-span portals with pinned and fixed bases, and one of a two-span two-storey building frame.

There has been close contact between Lehigh University and the University of Cambridge in the development of plastic design; Dr. Beedle himself spent some months at Cambridge in 1949. It is not surprising therefore that the methods of analysis and design are very similar to those already established in this country, nor that extensive reference is made throughout the book to the work of Professor J. F. Baker and the various members of his research team.

The book can be well recommended to University students and structural designers for whom it has been especially written.

F. A. PARTRIDGE

Welding
RESEARCH

B.W.R.A. REPORT

Alternating Torsion Tests on Welded Box Sections

SECOND INTERIM REPORT OF AN INVESTIGATION OF THE FATIGUE STRENGTH OF WELDED THIN GAUGE CONSTRUCTIONS

Thin gauge box sections in mild steel, made from pressings welded together, are common units of construction in the motor car industry. This report gives the results of alternating torsion fatigue tests on several specimens welded by the carbon-arc, metal-arc, and spot welding processes. These complement the results of alternating bending fatigue tests already reported.

The beam specimens were tested in a specially designed resonance rig, and the theory of the oscillating system is described in an appendix. The relative strengths of the specimens are given in terms of the torque sustained for 10 million cycles.

A completely closed section welded continuously by the carbon arc process gave good results, as did the spot welded specimens, which had previously been shown to be superior in bending tests. Sections that had been intermittently welded by the metal-arc process did not give such satisfactory results.

By R. P. Newman,
T. R. Gurney,
and G. Coates

THIS report describes part of an investigation which has been undertaken to provide information for the motor car industry on the fatigue behaviour of thin-gauge constructions in mild steel, fabricated by various welding processes. The detail design of such constructions may, of course, be influenced by the kind of welding process used, but in this investigation an attempt has been made to reduce design variables to a minimum. Thus, simple box-section specimens of uniform cross-section have been tested, but these are, nevertheless, representative of industrial practice in so far as the application of welding is concerned and, in fact, the specimens were manufactured by collaborating firms in the motor car industry.

Three series of tests were proposed for the investigation of the fatigue performance of these specimens:

(i) Alternating bending about the major axis of the section
(ii) Alternating bending around the minor axis
(iii) Alternating torsion.

This report deals with the last of these loading conditions. The two series of alternating bending tests have been reported elsewhere.[1]

General Description of Specimens

Material

The specimens were constructed from 16 s.w.g. deep drawing quality mild steel to specification EN.2A, all sheets being taken from the same heat. The specification limits for chemical composition given by BS.1449

Report FE.23/6/58 of the British Welding Research Association, issued to members in March, 1959.

Mr. Newman is Chief Research Engineer, and Mr. Gurney a Senior Research Officer with the Association. Mr. Coates was also a Senior Research Officer at the time the work was carried out.

Table I

Tensile properties of 16 s.w.g. EN2A steel sheet

Specimen	*Ult. tensile strength, tons/sq.in.*	*Elong. on 2 in., %*
1	19·50	46·9
2	19·22	46·9
3	19·44	48·45
4	19·20	46·9
Average	19·34	47·28

for this steel are: C, 0·12%; Mn, 0·50%; S, 0·05%; P, 0·05% (all max.)

This standard does not specify any mechanical tests but the results of tensile tests carried out on samples cut from the sheets are given in Table I.

Design and fabrication

Five types of specimen were tested, the major dimensions of the cross-sections of each being nominally $2\frac{1}{2}\times3\frac{3}{4}$ in. The designs, with detailed dimensions, are shown in Fig. 1. Each type of specimen was made from two pressings consisting basically of two equal or unequal channels welded together to form a rectangular box section. The two longitudinal joints in each specimen were made by various welding processes, as follows:

(*a*) Continuous edge weld on close butted flanged edges of channels, made by an automatic carbon-arc process without filler
(*b*) Manual metal-arc intermittent fillet welds, 3 in. long with 3 in. spaces, made at the corners of the section
(*c*) Spot welding, with welds at 1 in. pitch
(*d*) Similar to section (*b*) but, by using two channel pressings more nearly equal in size, the joints were removed from the corners of the section to a position nearer the centre of the $2\frac{1}{2}$ in. sides. The length and spacing of the manual metal-arc welds were the same as for section (*b*)
(*e*) Spot welding, with welds at 1 in. pitch, as in section (*c*).

The length direction of all specimens corresponded with the direction of rolling of the sheet. The length of 3 ft was considered to be a reasonable compromise between the conditions required for resonance testing and the need to have an adequate representation of the forms of welded joint to be investigated.

Sectional properties

The effective polar moment of inertia J of each section was determined experimentally by measuring the twist under an applied static torque. The values of J calculated from the torque-twist curves were:

Section	*Polar moment, J, in.⁴*
(*a*) Automatic carbon-arc welds	1·57
(*b*) Intermittent fillet welds	1·31
(*c*) Spot welds	1·43
(*d*) Intermittent fillet welds	1·24
(*e*) Spot welds	1·30

Method of Testing

The specimens were tested under alternating torsion in a resonance rig designed primarily for use in this investigation.

The principle of the testing system is illustrated in Fig. 2. A mass M is mounted on bearings B, C, which permit it to rotate freely about a horizontal axis XY coincident with that of the specimen S. The latter has a driven end D, rigidly attached to the mass M, and a fixed end F. An oscillator capable of generating torsional vibrations about the common axis is located in mass M, the inertia and torsional stiffness of which are large compared with the corresponding properties of the specimen.

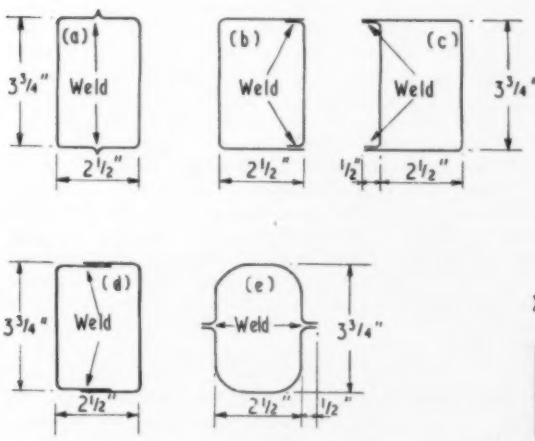
The theoretical background is given in some detail in the Appendix, where it is shown that the resonance frequency for low damping is very close to the natural resonance frequency

$$\omega=2\pi f=\sqrt{\frac{C.g}{I_0L}}$$

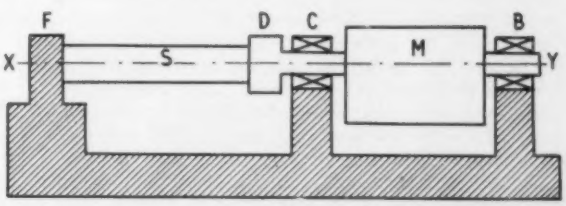
where $C=GJ$ is the torsional rigidity of the specimen, I_0 is the moment of inertia of the oscillator unit about the axis of the specimen and L is the length of the specimen.

The oscillator inertia I_0 was estimated from an approximate calculation and by timing when it was supported by a bifilar suspension. Using the value $I_0=3620$ lb/sq. in. so obtained, and putting $G=11{,}700{,}000$ lb/sq. in. and $L=36$ in. gives $\omega=251$ sec^{-1} (2400 c/min) for a theoretical perfect box section $3\frac{3}{4}\times2\frac{1}{2}$ in. and 0·064 in. thick.

The actual resonant frequencies obtained were less than this, since a short length of shaft for use as a torquemeter was connected between the specimen and

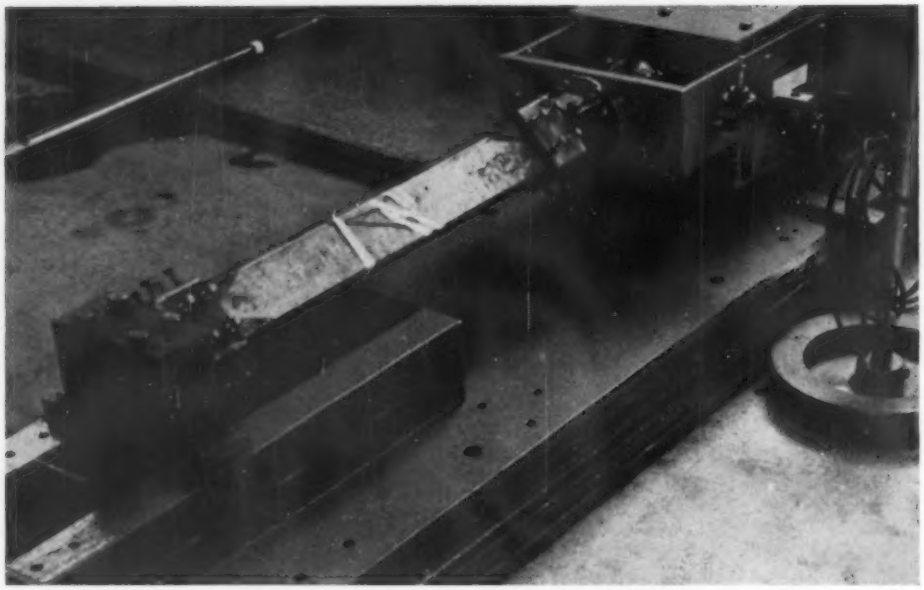


1—*Design of 16 s.w.g. box sections; (a) continuous carbon-arc welds; (b) metal-arc welds, 3 in. weld, 3 in. space; (c) spot welds at 1 in. pitch; (d) metal-arc welds, 3 in. weld, 3 in. space; (e) spot welds at 1 in. pitch*



M = Mass (oscillator) B, C = Bearings S = specimen
D = driven end F = fixed end

2—*Principle of oscillating system*



3—*Alternating torsion test rig (torque meter not fitted)*

the fixed tail-stock. This increased the effective specimen length and reduced the natural resonant frequency to about 1700 c/min.

The equipment is illustrated in Fig. 3, with the oscillator unit at the right-hand side. It comprises two similar semi-cylindrical rotors revolving in the same direction at the same speed, but 180° out of phase with one another so that the resultant forces produce an alternating couple. The revolving parts are enclosed in a rectangular box unit. One rotor is driven directly by a flexible coupling from a d.c. motor, while the second rotor is coupled to the first by an idler gear. The oscillator unit projects beyond the bearing nearest to the specimen and carries a steel driving block with a square hole, which engages with a square end-coupling on the specimen end-clamp fittings.

Special precautions were necessary in clamping the specimen ends, since under torsional loading the stress levels are uniform throughout the length of the specimen. It would, for example, be impossible to drill holes in, or weld attachments to, any of the specimen ends without causing stress concentrations which would induce premature fatigue failure. Therefore the end-clamp fittings were hollow steel box units which enclosed the ends of the specimens and clamped them to fitted internal hardwood plugs by steel bolts, the pressure of the bolts being transmitted to the outer surface of the section by tapered steel fingers, which reduced any tendency to develop high local stresses. This method of attachment proved to be completely satisfactory and no failures in the gripped portions of the specimens occurred.

At all selected amplitudes the test rig maintained reasonably stable conditions without control after a short initial period of running. Nevertheless it was necessary to provide some means of avoiding a drift in amplitude and this was done by using a mechanical control switch, actuated by the vertical displacement of the oscillator box frame. The method of operation of this type of control has been described by Percival and Weck.[2] Cut out-switches were used to stop the rig when amplitudes quickly increased, as happened at failure, and these also were operated by the displacement of the box frame.

An attempt was made, by means of strain measurements under static load, to derive the stress distribution in each box section due to an applied torque. The measurements were taken with a $\frac{1}{4}$ in. base-length Johansson extensometer, positioned at successive stations around given sections of each member. Whilst it was clear that peak stress concentrations at discontinuities could not be accurately determined in this way, the measurements were made to check the possibility of using a stress criterion for the purpose of comparing fatigue behaviour. The strain measurements indicated, however, that a load criterion would be more effective. Not only were there the expected variations in stress distribution pattern between different box sections, but local disturbances gave rise to apparently random variations in a given section. Measurements taken from one side of a box-section would, of course, suffer from the influence of warping and this was most marked in the intermittently welded specimens if sections taken through welds or between welds were compared.

Fatigue Test Results

The fatigue test results are summarized in Table II, and curves for each series, plotting the applied torque against number of cycles are compared on a common diagram Fig. 4.

As was to be expected, section (*a*), with its continuous carbon-arc welds giving a completely closed

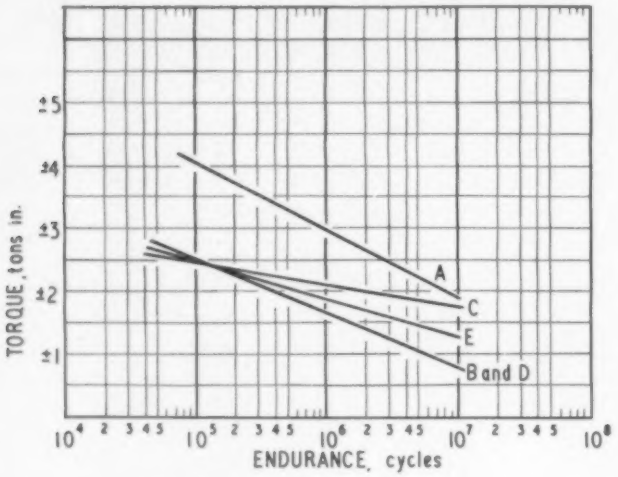
Table II

Summary of test results

Section (see Fig. 1)	*Specimen No.*	*Torque, tons-in.*	*Million cycles to failure*	*Remarks and details of failure*
(*a*)	AT–1	±2·3	3·949	Fracture from surface discontinuity in weld
	AT–2	±2·7	5·853	
	AT–3	±3·5	0·253	3 fractures from an area showing lack of weld penetration
	AT–4	±3·0	3·204	As AT–1
	AT–5	±3·2	0·610	Fracture from point of poor weld penetration
	AT–6	±2·6	2·513	2 fractures from weld discontinuities and fracture along weld between them
	AT–7	±2·1	2·133	As AT–1
	AT–8	±2·1	5·717	As AT–1
(*b*)	BT–1	±1·3	3·976	3 fractures from ends of fillets
	BT–2	±1·1	2·848	4 fractures from ends of fillets
	BT–3	±0·9	6·015	2 fractures from ends of fillets
	BT–4	±2·0	0·403	As BT–3
	BT–5	±0·75	10·002	Unbroken
	BT–6	±2·3	0·173	As BT–3
	BT–7	±1·7	1·007	As BT–3
	BT–8	±0·75	11·294	Unbroken
(*c*)	CT–1	±2·0	1·301	Fracture through spot weld
	CT–2	±2·3	0·250	Failure of 4 adjacent spot welds and cracks through 2 other spot welds
	CT–3	±1·7	10·453	Unbroken
	CT–4	±1·9	2·739	3 fractures through spot welds
	CT–5	±1·8	4·492	2 fractures through spot welds and tearing out of 6 spot welds between them
	CT–6	±1·7	9·571	2 fractures through spot welds and tearing out of 3 spot welds between them
	CT–7	±2·5	0·048	Failure of 10 adjacent spot welds; no plate cracks
(*d*)	DT–1	±2·3	0·180	6 fractures, all from ends of fillets
	DT–2	±0·75	10·128	Unbroken
	DT–3	±2·0	0·385	2 fractures from ends of fillets
	DT–4	±1·5	2·805	As DT–3
	DT–5	±1·3	2·771	3 fractures from ends of fillets
	DT–6	±1·1	3·921	5 fractures from ends of fillets
	DT–7	±0·9	9·228	As DT–6
(*e*)	ET–1	±2·0	0·659	2 fractures at edges of spot welds
	ET–2	±1·5	8·166	3 fractures through spot welds and 1 at edge of weld
	ET–3	±2·5	0·111	2 cracks $\frac{1}{2}$ in. and $4\frac{1}{2}$ in. from centre adjacent to spot welds
	ET–4	±1·4	9·215	1 fracture through spot weld and 2 fractures at edge of spot welds
	ET–5	±1·3	10·406	Unbroken
	ET–6	±1·7	2·005	Crack 9 in. from centre through spot weld, second crack 13 in. from centre on edge of spot weld
	ET–7	±1·3	11·840	Unbroken
	ET–8	±2·3	0·099	2 fractures at edge of spot welds

section, proved to be somewhat superior to the other sections, particularly when judged at comparatively low life (up to 1 million cycles), although this advantage was lost at 10 million cycles. The torque value corresponding to the limit of 10×10^6 cycles was not, however, established clearly owing to the scatter in results between 1 million and 10×10^6 cycles. Table II shows that in nearly every case fracture was initiated by a singular type of discontinuity in the weld in the form of an elongated crater (Fig. 5) which occurred intermittently along the weld seam. This fault, traced to the welding operation, was found to be due to a discontinuous motion of the traversing gear under the welding head of the automatic plant.

The fatigue results for the spot-welded specimens (sections (*c*) and (*e*)) are notable for their lack of scatter, and it is apparent that this form of construction is superior to the intermittent fillet welded form. Many of the fractures obtained in the spot-welded specimens appeared to be initiated within welds rather than at the edge of welds. Some failures of the latter kind were observed in section (*e*), but the through-weld mode was common in section (*c*). A similar result had earlier been obtained for the alternating bending tests,[1] in which it was shown that the initiation of fractures within spot welds could be attributed to internal defects. Radiographic examination and sectioning had established the presence of pores up to $\frac{1}{32}$ in. dia. in the welds, and in one case fatigue failure appeared to be associated with initial cracking in a weld nugget. With some of the present specimens, notably CT-2 and CT-7, it was possible to examine the



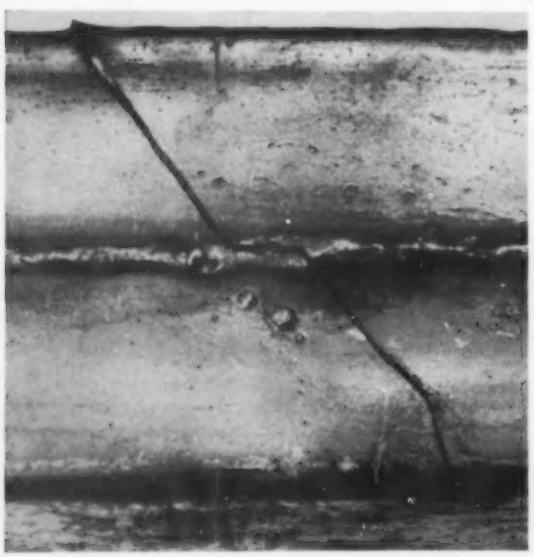
4—Comparison of results from all test series

sheared interface of several weld nuggets; pores of similar size occurred quite generally, owing to loss of metal by splashing. In addition, one or two welds contained irregular star cracks visible under a magnification of 10. Thus, while there is no evidence to suggest any significant loss of strength from such defects, it is probable that they caused the through-weld failures noted in section (*c*) specimens, a typical example of which is shown in Fig. 6.

In all the carbon-arc (section (*a*)) and metal-arc (sections (*b*) and (*d*)) specimens the cracks were at approximately 45° to the axis (*i.e.* the normal type of torsion failure). With the spot-welded members, however, the 45° crack occurred when propagating away from the welded flanges, otherwise the cracks tended to run straight to the edge of this flange from the point of initiation. An interesting mode of failure was obtained in specimens CT-2 and CT-7. This consisted of the shearing of several adjacent spot welds without any attendant cracking of the sheet material, although in specimen CT-2, cracks in the sheet did occur at other locations.

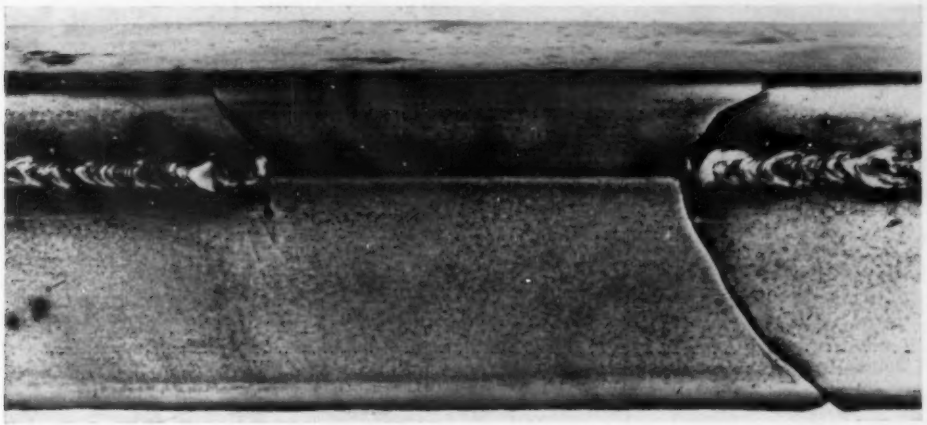
The results of the tests on the intermittent, metal-arc welded sections (*b*) and (*d*) indicate that the position of the longitudinal joints has no effect on the fatigue characteristics in torsion, the fatigue curves for the two sections being coincident. In every case fracture started at the ends of the intermittent welds and sometimes several cracks were initiated in one specimen (Fig. 7).

The relative strengths of the sections in terms of the torque sustained for 10×10^6 cycles are given in Table III and are expressed as percentages of the strength of section (*a*). For this section the relevant strength value was not determined precisely because of scatter, but a lower limit curve was drawn (Fig. 4) ignoring one result in which the crater defect was markedly severe.



5—Failure in section (a) from weld crater

6—Failure through spot weld in section (c) specimen



7—Multiple cracking in section (d) specimen

Table III

Comparison of strengths of sections

Section	*Applied torque corresponding to 10×10^6 cycles, tons-in.*	*Strength as percentage of section (a)*
(*a*) Automatic carbon-arc welds	1·8	100
(*b*) Intermittent fillet welds	0·75	42
(*c*) Spot welds	1·7	95
(*d*) Intermittent fillet welds	0·75	42
(*e*) Spot welds	1·3	77

Table IV

Comparison of T/J values

Section	*T/J*	*Percentage of section (a)*
(*a*) Automatic carbon arc welds	1·14	100
(*b*) Intermittent fillet welds	0·57	50
(*c*) Spot welds	1·19	104
(*d*) Intermittent fillet welds	0·605	52
(*e*) Spot welds	1·00	87

The order of merit indicated by Table III refers to applied loading. By taking values of T/J for each section a comparison can be made on a nominal reference stress basis, as shown in Table IV, in which the value of T again refers to 10×10^6 cycles. Because of the small differences in torsional stiffness, the general comparison is similar to that of Table III, notably in that the two intermittently welded sections suffer almost as large a reduction in the nominal reference stress (T/J) as they do in load capacity.

Conclusions

Since the torsion tests were the third of a series of loading conditions on the same set of five sections, it is useful here to consider performance in terms of the overall behaviour of the sections.

As in the earlier alternating bending tests, the torsion tests have shown that intermittent metal-arc welded construction is relatively weak under fatigue loading if the welds are located in stressed areas. Thus section (*b*) in torsion and in bending about either the major or minor axis, and section (*d*) in torsion and in bending about the major axis suffer a significant loss of strength because of the stress concentration effects associated with the ends of intermittent welds. With the intermittent welds near the neutral axis in bending, as they were for section (*d*), bending about its minor axis, fatigue behaviour can include the intervention of buckling and in the present case no real fatigue data were obtained.

For torsion loading the completely closed section made by carbon-arc welding (section (*a*)) gives good results, but is not definitely superior to the spot-welded form of section, to section (*c*) design. It is possible that some improvement in section (*a*) could be made by eliminating the discontinuities in the weld seam, but in bending about the major axis the section had the lowest strength of the five tested, and for this form of loading considerable improvement would be necessary to bring it to the level of section (*c*).

The sections with spot-welded flanges, (*c*) and (*e*), performed well under torsion loading, particularly section (*c*) which, at 10 million cycles, might be accounted as sensibly the same as section (*a*). If the results of the bending tests are also considered, the spot-welded form of construction may be regarded as having the best overall performance under the three loading conditions.

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APPENDIX

Theory of Oscillating System

For a driving torque of moment $M=M_0 \cos pt$ (in which M_0 is the amplitude of the couple, $p=2\pi\times$ frequency, and t=time), and end mass having a moment of inertia I_0, a bar of torsional stiffness C and length L, the angular deflection at the driving end is given by:

$$M=M_0 \cos pt=\frac{C\theta}{L}+K\theta'+\frac{I_0\theta''}{g} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where K is a damping factor and g is the acceleration due to gravity.

The solution of this differential equation is:

$$A=\alpha \cos(pt-\phi) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\alpha=\frac{M_0}{\sqrt{(C/L-I_0p^2/g+K^2p^2)}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\phi=\frac{Kp}{(C/L+I_0p^2/g)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This is interpreted physically as a sinusoidal oscillation lagging by the phase angle ϕ behind the driving torque. The amplitude of the oscillation reaches a maximum near the natural resonance frequency (*i.e.* for no damping) where

$$p=\sqrt{(Cg/I_0L)}=\omega \text{ (say)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

To simplify these equations, it is convenient to write

$$p=\lambda\omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$K=\mu I_0\omega/g \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Where λ and μ are dimensionless parameters, λ being proportional to the driving frequency and μ to the damping factor.

$$\text{Then } \alpha=\frac{M_0g}{I_0\omega^2\sqrt{\{(1-\lambda^2)^2+\mu^2\lambda^2\}}} \quad . \quad . \quad . \quad . \quad (8)$$

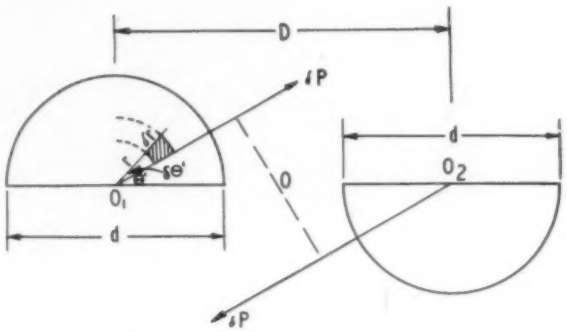
$$\tan\phi=\frac{\mu\lambda}{1-\lambda^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Considering firstly equation (9), it will be seen that, irrespective of the value of the damping coefficient μ, ϕ assumes the values 0°, 90°, 180° where $\lambda=0$, $\lambda=1$, and $\lambda\rightarrow\infty$ respectively. This means that, at very low frequencies, the amplitude is in phase with the driving oscillator, it lags a quarter of a cycle behind at the natural resonant frequency, and half a cycle behind at very high frequencies.

At this stage it is not possible to derive the relationship of the angular amplitude α to λ, for the output of the oscillator depends on frequency, (*i.e.* M_0 is a function of λ): it is this feature which makes the resonance conditions different from those of a traditional fixed-torque driven oscillator, as, for instance, that referred to by Karman and Biot.[3]

To determine M_0, it is necessary to consider the forces exerted by the two hemicylindrical rotors. In Fig. 8 the rotors (axes 0_1, 0_2) are shown in the position in which the maximum torque is exerted, and are assumed to be revolving in an anti-clockwise direction with angular frequency p.

If ρ is the surface density (weight per unit area) of the rotor (assumed to be of uniform cross-section along its axis of rotation), the centrifugal force δP exerted by the oscillator element $r.\delta\theta'.\delta r$ is



8—Section through idealized rotors

$$\delta P=\frac{(\rho r.\delta\theta'.\delta r.)\, rp^2}{g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The couple formed by a pair of such elements about an axis through 0 is

$$\delta(\Delta M_0)=\delta P.D \sin\theta'$$

Where D is the distance apart of the rotor axes 0_1 and 0_2.

This gives

$$\delta(\Delta M_0)=\frac{\rho Dp^2 (\sin\theta'.\delta\theta')\,(r^2.\delta r)}{g}.$$

Integrating for a semi-annulus of radius r and for a rotor of diameter d:

$$M_0=\frac{\rho Dp^2}{g}\int_0^{\pi}\sin\theta'.\delta\theta'\int_0^{\frac{d}{2}}r^2.\delta r$$

$$\text{Hence } M_0=\rho\frac{Dp^2d^3}{12g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

This may be further simplified if the mass of the two rotors m is substituted for $\rho\pi d^2/4$ whence

$$M_0=\frac{1}{3\pi}\cdot\frac{mDp^2d}{g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

The above calculation has assumed that the rotor axis $0_1\,0_2$ does not rotate around 0 or, in other words, that the peak output M_0 given by equation (12) is the torque developed if the oscillator is coupled to an infinitely stiff specimen. The output under conditions of oscillation likely to be obtained in practice will be similar.

Substituting this value of M_0 in equation (8) and writing $p=\lambda\omega$ yields

$$\alpha=\frac{mDd}{3\pi I_0}\left[\frac{\lambda^2}{\sqrt{\{(1-\lambda^2)^2+\mu^2\lambda^2\}}}\right] \quad . \quad . \quad . \quad (13)$$

The most interesting feature of this equation is that as $\lambda\rightarrow\infty$ the expression in square brackets tends to unity, so that at high frequencies

$$\alpha\rightarrow\alpha_{inf}=\frac{mDd}{3\pi I_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

As the expression for α_{inf} does not contain any quantities relating to either the specimen or the frequency, it is apparent that *the amplitude at high driving speeds tends to a constant value, which depends only on the dimensions of the oscillator*. The explanation is evidently that the output couple of the oscillator rotors increases as the square of the frequency, whereas the inertia forces resisting the couple increase in the same proportion, so that the two effects cancel out.

As a result, the general oscillation conditions may be expressed entirely in dimensionless parameters β, λ, μ in the form

$$\beta=\frac{\lambda^2}{\sqrt{(1-\lambda^2)^2+\mu^2\lambda^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

where $\beta=\alpha/\alpha_{inf}$, $\lambda=\rho/\omega$, $\mu=K/I_0\omega$ . . . . . (16)

The frequency for maximum amplitude ($p_{max}=\omega\lambda_{max}$) is of particular interest. By solving $\delta\beta/\delta\lambda=0$ it may be shown that

$$\lambda_{max}=[1-(\mu^2/2)]^{-\frac{1}{2}}$$

or $\lambda_{max}=1+(\mu^2/4)$ when μ is small.

Consequently, for light damping the greatest amplitude occurs for a frequency slightly higher than the natural resonance frequency.

Critical damping ensues when $\mu=\sqrt{2}$, as $\lambda_{max}\rightarrow\infty$ in this case.

When $\mu>\sqrt{2}$ the amplitude increases steadily with frequency and it is impossible to stimulate a resonance condition.

The frequency $\omega/\sqrt{2}$

For $\lambda=1/\sqrt{2}=0{\cdot}707$, β takes the value $(1+2\mu^2)^{-\frac{1}{2}}$, which for small values of μ is almost unity. Consequently for light damping the amplitude at $1/\sqrt{2}$ of the natural resonance frequency is the same as that to which the amplitude tends at very high driving frequencies.

A family of curves illustrating the relationship between β and λ for various values of μ is plotted in Fig. 9.

Dynamic multiplier

A factor sometimes referred to in resonance systems is the dynamic torque multiplier γ which may be defined, for a particular frequency, as the ratio of the static torque necessary to produce the deflection to the torque output of the oscillator. Hence:

$$\gamma=M_s/M_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

For the numerator, $M_s=C\alpha/L$

and for the denominator $M_0=\frac{1}{3\pi}\cdot\frac{mDp^2d}{g}$ from eq.(12)

$=I_0\,\alpha_{inf}\frac{p^2}{g}$ from eq.(14).

Hence (in non-dimensional units)

$$\gamma=\frac{\alpha}{\alpha_{inf}}\cdot\frac{Cg}{I_0Lp^2}=\frac{\beta}{\lambda^2} \quad . \quad . \quad . \quad . \quad (18)$$

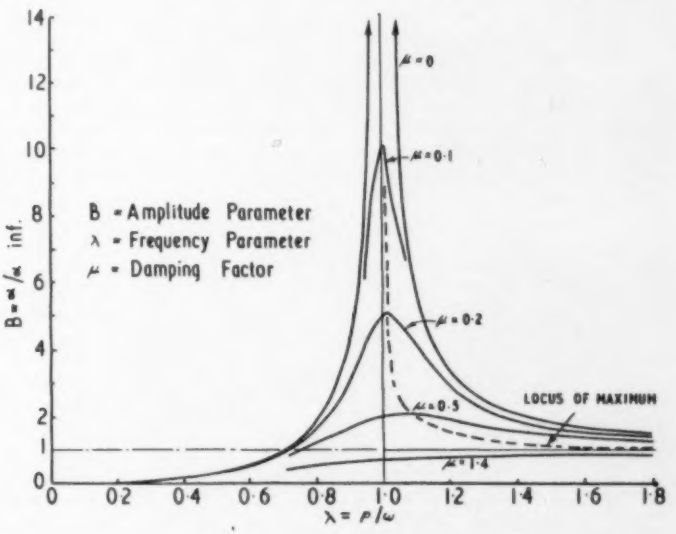
From equation (15) is obtained, therefore,

$$\gamma=1/\sqrt{\{(1-\lambda^2)^2+\mu^2\lambda^2\}}.$$

At the natural resonance frequency ($\lambda=1$), this is $1/\mu$. The maximum value is $\gamma_{max}=1/\mu\sqrt{\{1-(\mu^2/2)\}}$. at $\lambda=\sqrt{\{1-(\mu^2/2)\}}$.

For very slight damping ($\mu\ll1$)

$\gamma_{max}\simeq1/\mu$ at $\lambda\simeq1$.



9—*Theoretical resonance characteristics*

B.W.R.A. REPORT

By T. M. Charlton, M.A., B.SC. (ENG.), A.M.I.MECH.E.

A Test on a Two-Bay Pitched Roof Portal Structure with Buttressed Outer Stanchions

The report describes a test on a steel portal structure with rigid welded joints. The aim was to investigate the influence of instability of relatively slender centre stanchions on the collapse load of a two-bay portal under asymmetrical loading. In fact, the effect of this instability was masked by the increase of resistance to deformation caused by strain hardening, and so it appears that the simple plastic theory can be confidently used to predict the behaviour of this form of frame.

THIS report is concerned with the ninth of a series of tests to destruction of steel portal structures with rigid welded joints, as part of a programme of research into the plastic collapse behaviour of steel structures. The object of the test was to investigate the possible reduction in the collapse value of an unsymmetrical system of loading applied to the rafters of a two-bay pitched roof portal structure, due to the instability of slender centre stanchions. The outer stanchions of the structure were buttressed to prevent any significant movement of the eaves.

The test was carried out at the Abington Research Station of the British Welding Research Association. The arrangements for the test and method of loading were generally similar to those of previous tests.[1, 2]

Structure and Testing Gear

Details of main frames

The details of the two main portals of the structure, which were 12 ft apart between centres, are as shown in Fig. 1. The span of each bay was 16 ft, the height to eaves was 8 ft, and the rafters were inclined at 22½° to the horizontal. The eaves beams were 6 × 3 in. × 12·4 lb channels and the central valley beam was a 3 × 3 in. × 8·5 lb R.S.J. At intermediate points of the rafters the portals were braced together by 3 × 1½ in. purlins and the adjacent ridge purlins were strapped together at intervals of 2 ft along their length to form substantial ridge beams. In addition, cross bracing of ⅝ in. dia. steel bar was provided in the plane of the centre stanchions.

The feet of the stanchions were profile-welded to 1 in. thick mild steel baseplates held by ¾ in. dia. bolts to foundation beams clamped to a concrete slab, so as to approximate sufficiently closely to rigid foundation conditions. The foundations of the centre stanchions were heavy compound beams (Figs. 3, 4, and 5). The profile welds at the feet of the centre stanchions were ¼ in. leg at the flanges and ⅜ in. leg

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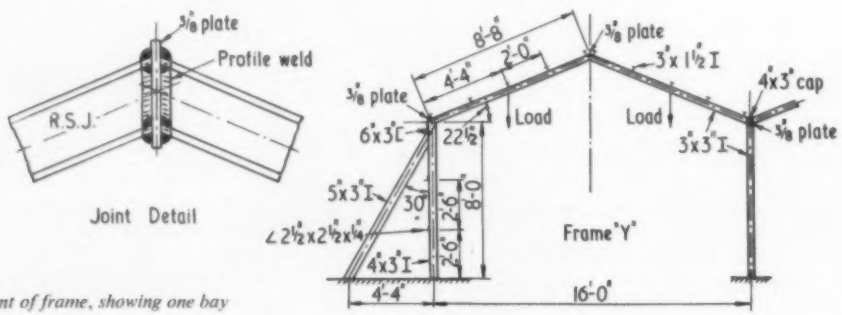


1—*General arrangement of frame, showing one bay*

2—*Side view of structure: frame* X *in foreground*

at the web, corresponding to throat thicknesses of 0·166 in. and 0·13 in. respectively.

The apex and eaves joints between rafters, and between rafters and outer stanchions, respectively, were made by cutting the members to the specified angles and connecting them by profile welds to the faces of $\frac{3}{8}$ in. mild steel plates, as shown in Fig. 1. The valley joints were made by profile welding the adjacent ends of the rafters, cut to the specified angles, to the flanges of short pieces of 4×3 in. R.S.J. These were profile welded to $\frac{3}{8}$ in. plates at the top of the 3×3 in. stanchions for accommodating the ends of the valley beam. All the profile welds were of $\frac{1}{4}$ in. leg at the flanges and $\frac{3}{16}$ in. leg at the webs so as to reproduce the cross-section of the faces of the sections as cut to enable the full plastic moment to be transmitted.

Care was taken to ensure that there were no laminations in the base and rafter joint plates.

All of the welds were made with 6 and 8 s.w.g. Code E.317 electrodes using an a.c. open-circuit voltage of 80 V.

Three test specimens were cut from undeformed lengths of the 3×3 in. rafters and centre stanchions for laboratory tests, to determine accurately the flexural rigidity and full plastic moment of the material used.

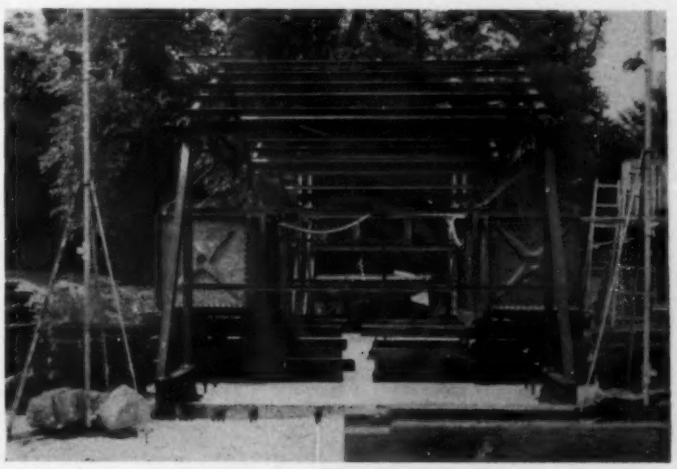
Erection of the structure

The stanchions were erected first and were tack-welded to their baseplates after checking for alignment and uprightness. The apex joints of the four pairs of rafters were made by site welding with the rafters horizontal. The pairs of rafters were then hauled into position on the stanchions and fixed by tack-welding. After alignment had been checked, the profile welds at the stanchion baseplates and ends of the rafters were completed, the ridge members and purlins were welded in position, and the cross bracing in the plane of the centre stanchions was assembled by cutting to the correct length and welding.

Loading gear

Equal concentrated vertical loads were applied at the centre of each rafter of one bay by means of loading tanks suspended by beams and links from lugs welded to the centre purlins (Fig. 2) in the manner described previously.[3] Each tank and its beam and links weighed approximately 1 ton. Increments of dead load were made up also by steel billets, each of which weighed approximately 2 cwt, and lengths of scrap caterpillar track, each weighing approximately 60 lb. Sufficient increments of load were weighed out carefully before the test and flexible pipes were run from overhead tanks to the loading tanks, as shown in Fig. 2, so that water could be used for the final increments of load. In this way there was no need for anyone to be close to the structure when it collapsed.

At the beginning of the test the loading tanks were supported by baulks of timber so that initial readings



3—*End view of structure*

of deflection could be taken with the structure unloaded except for the weight of the tank suspension beams and links.

Instrumentation

The longitudinal deflections of the tops of the stanchions were measured by vernier scales mounted on stands remote from the structure (Fig. 3). The verniers, which were capable of measuring movement as small as 0·01 in., were attached to the stanchions by fine stranded wire (7–0·008 in. dia., high-tensile steel) tensioned by 10 lb weights suspended over pulleys on the stands.

4—Centre stanchion of frame X after collapse

The vertical deflections of the apices, and of the rafters at the points of application of the loads, were measured by observing suspended black plastic scales with white graduations in $\frac{1}{10}$ in. (Fig. 4) through fixed theodolite telescopes. Each scale was kept vertical by loading it with a 10 lb weight.

The lateral movement of the double ridge purlins of the loaded bay and of the purlin connecting the centres of the outer rafters of this bay was observed by means of horizontal plastic scales fixed to these members, viewed through a theodolite telescope.

To detect the onset of plasticity, the members of the portal X of the structure were coated with plumbers' resin at the ends, centres, and apices of the rafters and at the top and bottom of the centre stanchion.

No instruments were necessary for measuring the loads applied to the structure because the magnitude of each increment of load was determined before the test.

Choice of Loading System

Any system of unsymmetrical loading of the structure, which would cause bending of the centre stanchions, could be used to attain the desired conditions, but the amount of equipment necessary and the duration of the test had also to be considered. The obvious system of loading seemed to be one whereby the rafters of only one bay were loaded, since this would cause severe deflection of the centre stanchions. Such a system, consisting of equal concentrated loads at the centres of the rafters of one bay, could be arranged without difficulty. Moreover, it seemed that this form of loading would produce a relatively complex and interesting mode of collapse (Fig. 5) with eight hinges.[4] Accordingly it was decided to proceed on these lines.

Description of Test

The first increment of load was applied by suspending the loading tanks from the structure simultaneously, which was done by removing the temporary supporting timbers with the aid of jacks. As soon as

5—Structure in collapsed condition

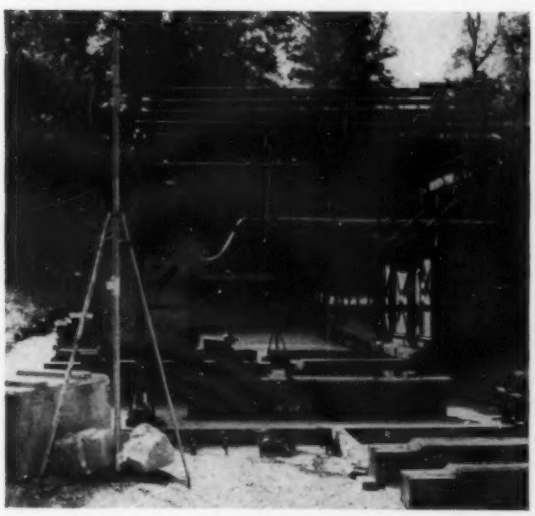
the deflections had been recorded, the second increment of load was applied and the deflections were read again. This procedure was repeated until the structure collapsed, when the total vertical load on each frame was 7·30 tons.

So as to pass through the elastic range fairly quickly, the first three increments of load were each 1 ton. These were followed by three increments of 0·5 ton, and after the first application local yielding was detected at the top of the centre stanchion by cracking of the resin on the flanges. The commencement of the formation of plastic hinges could also be detected by departure from linearity of the load/deflection curves, two of which were plotted as the test proceeded: the horizontal deflection at the top of the centre stanchion, and the vertical deflection of the apex of the loaded bay of frame Y. As departure from linearity of these curves was noticeable when the total load on each frame was 4·5 tons, it was decided to proceed from there in increments of 0·25 ton. When the total load on each frame was 6·5 tons, cracking of resin denoted the formation of the last plastic hinge (at the outer ends of the rafters of the unloaded bays), and it was decided to pause for one hour and afterwards to continue with increments of 0·125 ton. As creep was observed and collapse seemed imminent when the total load was 6·75 tons, it was decided to use water for the remaining increments until collapse occurred.

Unfortunately, when the first increment of 0·1 ton of water was applied, a weld failed at the valley joint of frame Y (between the inner flange of the 4 × 3 R.S.J. stanchion cap piece and the $\frac{3}{8}$ in. cap plate, which was followed by tearing of the web of the cap piece) because the weld was incomplete. Nevertheless, the test was continued by proceeding with the loading of frame X, which collapsed plastically at 7·3 tons, after the addition of six more increments of load, three of which were 0·1 ton and three 0·05 ton.

During the final stages of the test there was some lateral movement of purlins owing to local buckling of the rafters near the plastic hinges, as shown in Fig. 6. This movement increased with the premature failure of frame Y.

Throughout the test care was taken to ensure that loading of both frames of the structure was carried out evenly and simultaneously and that the load was distributed uniformly within the tanks. The intervals of time between increments of load, for the taking of readings, increased with the formation of plastic hinges, because then it was necessary to wait until creep became negligible, *i.e.*, less than 0·005 in./min.

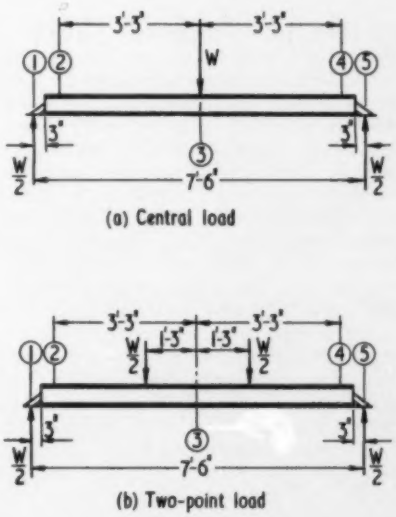


6—End view of structure after collapse

Control Tests

Three control test specimens were cut from the rafters of the unloaded bays of the structure after the test, so as to obtain adequate lengths of material which had not suffered permanent distortion.

The general arrangement adopted for the control tests is shown in Fig. 7. One specimen was tested under central concentrated loading and two were

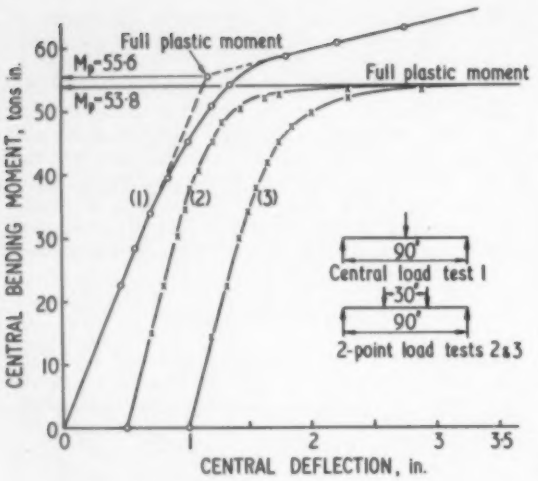


7—Arrangement of control beam tests

tested under two-point loading. The ends of the beams were supported through L-shaped brackets welded to them so as to distribute the shear over the end sections and to prevent instability of the compression flanges. Load measuring capsules were placed between the end brackets and the beam of the testing machine so that direct measurement of the forces applied at the ends of a control beam could be made.

The tests were carried out in an Amsler 500-ton compression testing machine, and dial gauges were used to measure deflections. Dial gauges 2, 3 and 4 enabled the actual deflections of a beam to be obtained, whilst gauges 1 and 5 enabled movement of the supports to be measured. The precise details of the equipment were similar to those described in an earlier report.[5]

For beams 2 and 3, which were tested under two-point loading, the whole of the length between the



8—Moment/deflection curves of control beam tests

loading points became completely plastic when the full plastic moment M_p of the section was attained. The magnitude of the bending moment on this part of the beam, at which the deflections continued to increase without increase in bending moment, was taken to be the full plastic moment of the section (Fig. 8). For beam 1, however, which was tested under a central concentrated load, the full plastic moment was developed directly under the load only, and not simultaneously throughout a finite length of the beam, as in the two-point load test. Consequently, strain hardening of the material occurred before large deflections were obtained and the central bending moment always had to be increased before there was an increase in deflection. In the strain-hardening range, the moment/deflection curve was nearly linear and the full plastic moment of the section was estimated by extrapolating this part of the curve backwards, in a linear manner, until it intersected the continuation of the linear portion of the curve, as shown in Fig. 8.

The properties of the section in these tests were consistent, as follows:

Beam No.	*Flexural Rigidity* E I, *tons/sq.in.*	*Max. Elastic Moment of Resistance* M, *ton-in.*	*Full Plastic Moment* M_p, *ton-in.*
1 (central load)	50,100	40·0	55·6
2 (two-point load)	50,100	40·0	53·8
3 (two-point load)	50,100	40·0	53·8

Accordingly, the following values were accepted for the 3×3 in. R.S.J. of the structure:

Flexural rigidity	50,100 tons/sq.in.
Maximum elastic moment of resistance	40·0 ton-in.
Full plastic moment	54·5 ton-in.

Results of Test

The horizontal deflections of the tops of the buttressed outer stanchions were neglible. The horizontal deflection of the top of the centre stanchion of frame X is shown graphically in Fig. 9, and the vertical deflections of the apices and points of application of the loads are shown in Figs. 10–13. The deflections of frame Y were similar to those of frame X until it failed.

Yield was observed as follows:

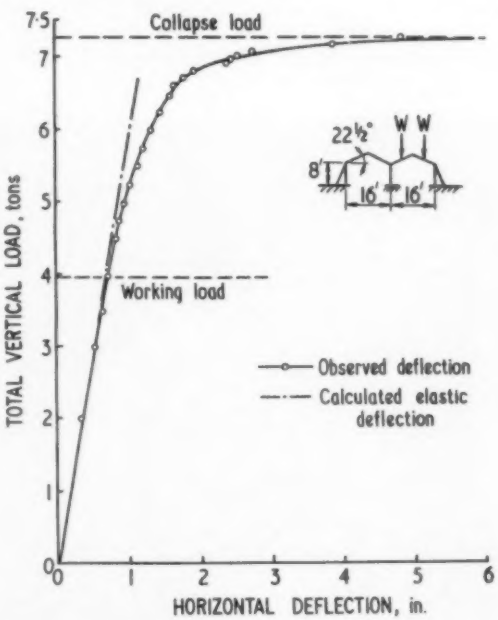
Load, tons	*Location*	*Hinge No.*
3·50	Top of centre stanchion	1
4·00	Eaves end of outer rafter	2
	Foot of centre stanchion	3
4·50	End of inner rafter of loaded bay	4
5·00	Apex of unloaded bay	5
5·25	Outer load point	6
5·75	Inner load point	7
6·50	Gable end of outer rafter of unloaded bay	8

As already mentioned failure of portal Y occurred prematurely at a load of 6·85 tons. Plastic collapse of portal X occurred at a load of 7·30 tons. This load was carried for some 15 min, during which time creep at an appreciable rate persisted until the loading tank landed on the ground. Distortion of the rafters and centre stanchions, from local instability of compression flanges in the final stages, can be seen in Fig. 6. This distortion of principal members also caused the bending of adjacent purlins as shown in Figs. 4 and 5.

Discussion

Elastic behaviour of the structure

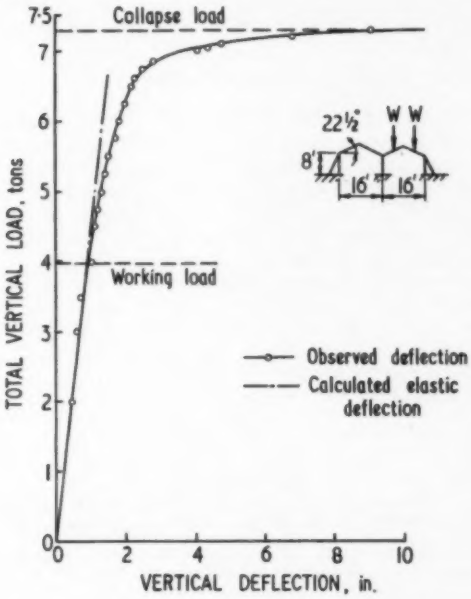
The deflections of the frames within the elastic range have been calculated,[6] using the value of the flexural rigidity for the 3×3 in. R.S.J. obtained from the control tests, and assuming that the feet of the centre stanchions were encastré. The corresponding load/deflection curves are shown in Figs. 9. There is very good agreement between the calculated and measured elastic deflections.



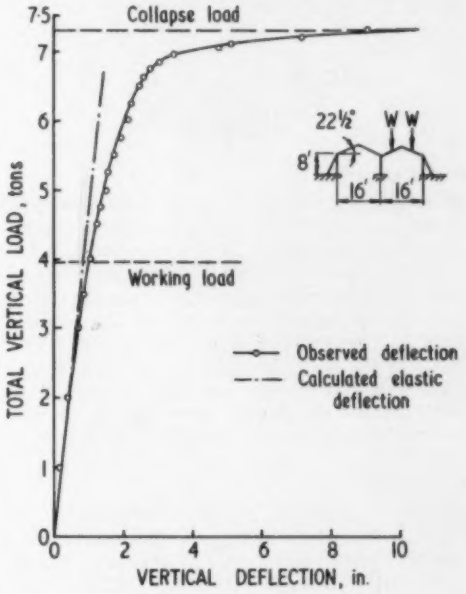
9—Horizontal deflection at top of centre stanchion, frame X

Plastic behaviour of the structure

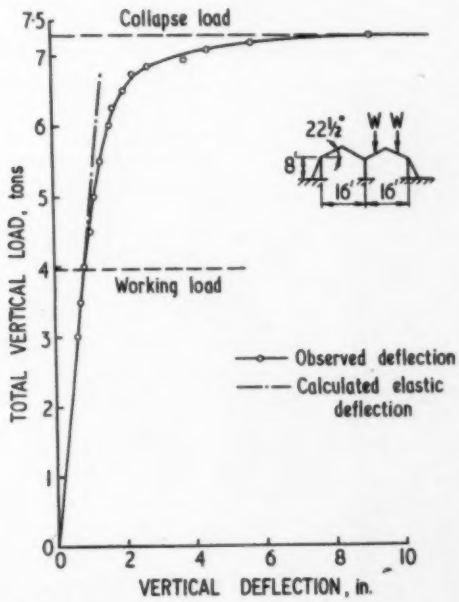
The theoretical collapse value of the system of loading used, based upon a full plastic moment of the 3×3 in. R.S.J. of 54·5 ton-in., is 6·96 tons for each frame. The fact that collapse did not occur until the load on each frame was 7·30 tons, or some 5% more than the theoretical value, is almost certainly due to the increase of the moments of resistance of the plastic hinges caused by strain hardening. Having regard, however, to the concentrated nature of the loading and the number of plastic hinges (eight) which formed, together with the shape of the bending-moment/deflection curves obtained by the control tests, a greater strain hardening effect might have been



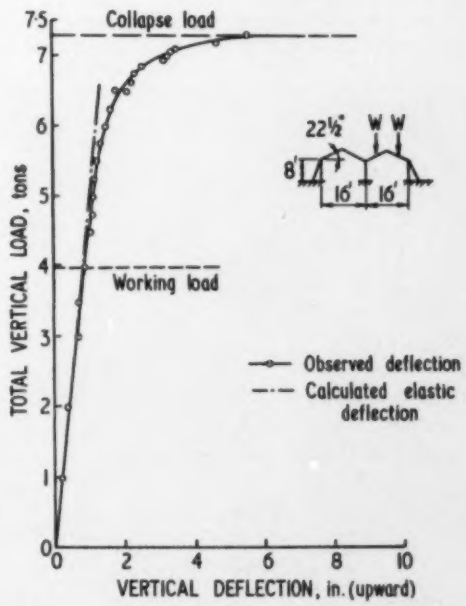
10—*Vertical deflection of rafter at inner load point, frame* X



12—*Vertical deflection of apex of loaded bay, frame* X



11—*Vertical deflection of rafter at outer load point, frame* X



13—*Vertical deflection at apex of unloaded bay, frame* X

expected. It seems likely, therefore, that the influence of strain hardening was partly offset by the tendency to instability of the centre stanchions. Thus, the latter would appear to lead to a reduction in the collapse load of the order of 4% on the basis of an empirical approach,[7] whereby the actual collapse load W_F is related to the load W_C which causes elastic instability of the stanchions, and the collapse load W_L calculated by the simple plastic theory, in the form:

$$\frac{1}{W_F} = \frac{1}{W_C} + \frac{1}{W_L}$$

Conclusions

Prediction of collapse load

Although the effects of strain hardening and the tendency to instability of compression members tend to complicate the behaviour of structures in the region of collapse, the results of this test are generally in accordance with the predictions of the simple plastic theory. Moreover, the results indicate once again that the simple plastic theory often provides a conservative estimate of the collapse load, owing to the stabilizing effect of strain hardening. The effect of both instability of the centre stanchions and local instability in members was too late to be of consequence.

Behaviour of joints

With the exception of the rafter-valley joint of frame Y, there was no failure or tendency to failure of any joint. The one failure which did occur was due to the accidental omission of a run of weld so that the plate and profile weld type of joint was, as in previous tests, shown to be of sufficient strength and rigidity.

Deflections under working load

For the particular system of loading chosen for this test the working value would be 3·95 tons, on the basis of the predicted collapse load of 6·96 tons and a load factor of 1·75. At the static working loading, therefore, the frames would be in the elastic range, and their deflection would not exceed the following values:

Horizontal deflection of top of centre stanchion	0·80 in.
Vertical deflection of rafter at points of application of load: inner	1·04 in.
outer	0·89 in.
Vertical deflection of apex of loaded bay	1·04 in.
Vertical deflection of apex of unloaded bay	0·88 in. (upward)

Deflections of these magnitudes are not excessive for many purposes and are in good agreement with the values predicted by conventional analysis.

Acknowledgments

The test described in this report forms part of a general investigation into the behaviour of rigid jointed frame structures being carried out by the Engineering Department of the University of Cambridge under the direction of Professor J. F. Baker, F.R.S., and with the support of the British Welding Research Association.

The author wishes to express his thanks to all those members of the staff and students of the Department who took part in the erection and testing of the structure, in particular to Mr. O. A. Halliday, who carried out the welding operations.

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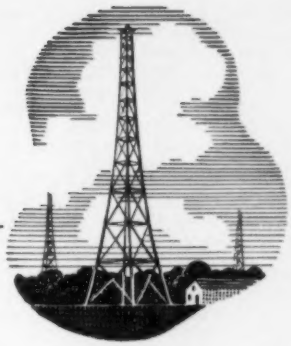
2. J. F. Baker and K. G. Eickhoff: "A test on a pitched roof portal", Report FE.1/35/53, BWRA (out of print).
3. T. M. Charlton and A. N. Schofield: "A test on a north light portal structure with footings in soil", Report FE.1/54/58, BWRA.
4. J. F. Baker, M. R. Horne and J. Heyman: "The steel skeleton", vol. 2, 1956, Cambridge University Press.
5. J. W. Roderick: "The behaviour of rolled steel joists in the plastic range", Report FE.1/25/51, BWRA (out of print).
6. T. M. Charlton: *Trans. N.E.C. Inst.*, 1958, vol. 74, pp. 163–188.
7. W. Merchant: *Struct. Eng.*, 1954, vol. 32, p. 185.

NEWS
and Announcements



News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

INSTITUTE ACTIVITIES

Changes on Council

Professor J. G. Ball, of Imperial College of Science and Technology, has accepted the Chairmanship of the Education Committee for 1959–60, in place of Dr. E. F. Gibbs.

Mr. W. E. Harriss, Honorary Treasurer of the Institute for many years, has taken the place of Mr. C. Humphrey Davy as Chairman of the Finance Committee.

Mr. E. Fuchs, Vice-President, has taken the place of Mr. E. Seymour-Semper as Chairman of the School of Welding Technology Committee.

Christmas Lecture to Young People

A novelty for the Institute will be a Christmas Lecture to Young People, to be given at the offices of the Institute on Tuesday, **5th January 1960,** at 11.0 a.m., when Professor Hugh O'Neill of University College, Swansea, will lecture on "*The Magic Arc.*"

Tickets will be required, and members whose sons and daughters are between the ages of 13 and 16 are invited to apply for tickets to the Secretary.

Spring Meeting 1960

The Spring Meeting of 1960 will be held from **9th to 11th May** at Droitwich.

The general theme of the meeting will be the novel welding processes and metal spraying. There will be an opening reception on the evening of Monday, 9th May, discussion meetings for the presentation of papers on the two following mornings, works visits on one afternoon, and a dinner on the Wednesday evening.

It is hoped to arrange demonstrations in connection with the papers on one of the afternoons and possibly on one of the free evenings. There will also be a display of trade literature and other small exhibits at the Winter Gardens, which will be the Conference Centre.

Electro-Slag Welding

The special one-day meeting on Electro-Slag Welding, held at the Institute on 1st October, was very well attended, and admission had to be limited to ticket holders only, because of the safety requirements at 54 Princes Gate.

The Chair was taken by Mr. J. F. Lancaster, Chairman of the Programme and Publications Committee. Before the two papers were presented Mr. Lancaster, on behalf of the Council, presented the C. W. Hill Prize for 1958 to Mr. A. J. A. Cooksey.

Two papers were then presented by Mr. J. A. Lucey and Mr. D. D. Smout, and by Mr. D. J. W. Boag and Mr. W. K. B. Marshall. (These appear in the September (pp. 396–405) and November (pp. 507–513) issues of the Journal, respectively.) After this, the Chairman called upon Professor N. N. Rykalin, of the Russian Academy of Sciences, to deliver a brief and most interesting address on the origin and development of this Russian process.

In this, he stated that the process was extensively used in Russian industry, especially for producing large fabrications from smaller prefabricated parts. The problems of the process had now been mastered for carbon and medium tensile steels and for some stainless steels and cast irons.

Professor Rykalin gave some interesting details of the process as developed in the USSR. Flux composition is most important, for on it depends the stability of the process; suitable compositions for various materials were quoted. He considered that normalizing after welding helped to improve the structure of the weld deposit, and referred to experiments using ultrasonic vibrations. These seemed to indicate that even much lower frequencies could have a beneficial effect on the structure.

Dealing with practical applications, Professor Rykalin stated that, as the process needed such a low current density in the welding wire (0·1 amp/sq.mm) it had been

Professor N. Rykalin being welcomed at the School of Welding Technology by the President, Mr. E. Seymour-Semper, and the Secretary, Mr. G. Parsloe.

possible to develop very large 'plate' electrodes, and these had been used successfully for welding thick plate such as in pressure vessels and other heavy constructions.

After tea there was a lively discussion, which continued until 6 o'clock.

Many of the questions were concerned with the problems associated with the coarse-grained structure of the deposited metal, and the various methods adopted to improve it. Professor Rykalin and the authors gave some convincing theories to explain the origin of the dendritic structures peculiar to electro-slag and submerged-arc processes, and demonstrated various methods that had been used to overcome the problem. A warning was given that local normalizing might set up further stresses that would make matters worse.

It was also indicated that distortion in the plane of the plates was virtually absent, and that vertical distortion (along the weld) could be controlled to a large extent by altering the speed of welding. Although, once started, the process was automatic, conditions could be altered during welding (which progressed upwards relatively slowly) if faults were indicated by the appearance of the weld below the water-cooled shoes.

During the discussion, Dr. Becker, the designer of some German electro-slag welding machines, showed slides of multi-electrode equipment as used for welding heavy locomotive frames.

Metal Spraying

As announced last year, the Institute is extending its activities into the field of Metal Spraying. As a first step, a Technical Committee on Metal Spraying has been set up and held its first meeting in October.

The personnel of the Committee is as follows:

J. Barrington Stiles (Metallizing Equipment Co.)
G. R. Bell (Wall Colmonoy Ltd.)
E. R. Bowers (Dorman Long (Bridge and Engineering) Ltd.)
G. A. Curson and *H. W. Fender* (Metal and Plastic Coatings Association)
J. Gallagher (Association of Metal Sprayers)
L. Jackson (John Thompson Beacon Windows Ltd.)
R. A. Parkes (Association of Metal Sprayers)
M. Riddihough (Deloro Stellite Ltd.)
A. D. Stacey (English Steel Corporation Ltd.)

Mr. Curson has joined the Programme and Publications Committee, to help in the introduction of papers on metal spraying into the programmes of the Institute and its branches. Similarly, Mr. Bell is representing metal-spraying interests on the Membership Committee, and Mr. Ballard on the main Technical Committee.

The new prospectus of the School of Welding Technology announces that the School Course on Metal Spraying, which was given last May, will be repeated in September 1960. This is a provisional announcement, and full details will be included in the prospectus covering April to December 1960.

A paper on metal spraying will be presented and discussed at a meeting of the Wolverhampton Branch on Friday, 26th February, 1960. It is also hoped to publish shortly in the Journal a paper on metal spraying, contributed by Mr. Ballard to the Netherlands Welding Society in September last.

Companies and individuals interested in metal spraying are invited to offer technical papers for publication in the Journal or for presentation at meetings of the Institute and its branches. News of developments and applications of the process will also be most welcome, and should be addressed to the Editor.

NEWS OF MEMBERS

J. C. Borland, A.I.M,. recently a Research Officer with the British Welding Research Association, has joined the United Kingdom Atomic Energy Authority. He is in charge of the Welding Laboratory at Culcheth, in the Development and Engineering Group. There, also, is another previous member of BWRA staff, Mr. H. Vaughan.

Obituary

The Council regrets to record the deaths of:

A. H. Best, formerly of the English Electric Co. Ltd., on 24th March. Mr. Best was one of the early members of the Midlands Branch of the Institute, and later he transferred his interests to the Wolverhampton Branch when it was formed out of the Midlands Branch. He took an active interest in Institute affairs, and for some years he served as a member of the General Purposes Committee.

H. Baxendale, on 4th July (Preston Branch, Assoc. Member 1950).

BRANCH NEWS

North London

In his Presidential Address, on Wednesday, 16th September, the new President of the Branch, Mr. R. W. Ayres, went into the problem of the great need that exists for Welding Engineers. Many firms do not avail themselves of the many blessings that welding can accord—quite often through ignorance—and a competent welding engineer could increase and improve production.

Mr. Ayres stated that he had had many years of experience in the welding field, and had always considered that industry should take good apprentices, give them specialized training in the various fields, send them for long courses to the welding equipment manufacturers, and encourage them to study at the technical colleges. All these were possible channels which would lead to them becoming first-class welding engineers.

The President then discussed various types of automatic welding and spot-welding techniques, and he claimed that his 'ideal type of man' for training as a welding engineer in this line of welding would be a mechanical engineer.

The address was well received by a good meeting of members and visitors, who entered into a short question time afterwards. R.B.W.

South London

At the end of the last session, the Branch Committee carried out a very successful experiment that might well be copied by other branches. This was a conversazione, held on 2nd June at 54 Princes Gate, at which some new welding processes were displayed. Representatives of the manufacturers were in attendance to discuss the equipment and the trends in the development of new welding processes.

The equipment shown included an electron-beam welder, guns for fine wire welding, apparatus for semi-automatic welding of mild steel, and examples of electro-slag welded joints and high-frequency welded aluminium tubes.

Electron-beam welding

The electron-beam welder is made under licence by Edwards High Vacuum Ltd., and is based on the original work of Stohr, of the Commissariat a l'Energie Atomique, Saclay, France (see *Welding and Metal Fabrication*, Oct., 1958, p. 366). Welding is carried out in a specially designed vacuum chamber at a pressure of less than 10^{-4} mm of mercury. An electron gun is used to produce a beam of electrons, which are accelerated by a high-tension supply and focussed, either magnetically or electrostatically to a point coinciding with the line of the intended weld. The impact of the electron beam produces intense local heating on a small target area. The weld is made by moving the workpiece so that the beam traverses the line of weld.

With this process very thin and refractory materials may be welded in a flux-free atmosphere, and without contamination.

Electro-slag welding

Examples of welds in thick plate, made by the Rockweld-Vus equipment and by the Quasi-Arc vertical Unionmelt process, attracted a good deal of interest. These processes have been described more fully in the November (pp. 507–513) and September (pp. 396–405) issues of *BWJ*, respectively.

Fine wire welding

Several examples of welding guns using fine wire were available; the American West-Ing-Arc (marketed in Great Britain as the Rowen-Arc by Rubery Owen & Co. Ltd.) and the Miget, and British models by Quasi-Arc Ltd., British Aluminium Co. Ltd., and the British Welding Research Association. All these created intense interest, and the demonstrators were kept busy replying to the many questions from visitors.

Development of the consumable-electrode gas-shielded processes has been confined mainly to applications on thicker materials, the welding of thinner gauges being limited to the gas welding and tungsten-arc processes. More recently, however, attention has been given to the welding of materials in thicknesses of the order of 16 s.w.g. By incorporating drive mechanisms in the gun itself and by introducing refinements in the arc control system, various manufacturers have been able to produce the guns demonstrated. They allow higher speeds to be used, with consequent decrease in distortion and in cost, and provide greater ease of

Demonstrating the Rowen-Arc fine wire gun in the vertical and overhead positions at the laboratories of the Northern Aluminium Co. Ltd.

operation. All the lightweight guns on show are more or less self-contained; each carries a small reel of wire, and only the cable and gas supply from the power source and control cabinet are extraneous.

A considerable amount of development work has been conducted on these guns, by the Northern Aluminium Co. Ltd., British Aluminium Co. Ltd., and the BWRA, and it is expected that the equipment will find increasing application for the welding of aluminium alloys and steel in the thinner gauges.

Semi-automatic steel welding

The Tubarc process, shown by Quasi-Arc Ltd., and the Comet CO_2 process, shown by Rockweld, both aim to provide the advantages of speed and low cost of the automatic arc-welding processes together with the flexibility of manual welding.

The Tubarc process uses the standard Lynx wire feed and control unit, but the electrode is a continuous hollow tube containing a core of granulated flux. Dual shielding by flux and carbon dioxide gas enable very high current densities to be used, thereby increasing welding speed and reducing distortion.

The Comet process similarly uses a composite electrode, made from folded strip in which the flux is entrapped. The process is available in both semi-automatic and fully automatic versions, and can be used for downhand and h.v. fillets and h.v. butts with very high rates of deposition. Three types of wire are provided, each in three sizes, one for operation on a.c. with low open-circuit voltage, one for operation on a.c. or d.c. suitable for dirty plate, and the third, with smaller amounts of flux, for welding in deep grooves without the need for cleaning between runs. The outstanding features of these processes are the high rate of deposition and the depth of penetration.

High-frequency welding

The tube mill and high-frequency welding plant installed by Elm Engineering Ltd., for the fabrication of aluminium alloy tubes, was briefly described in the April 1959 issue of *BWJ* (p. 185). A few examples of the products of this machine were shown, and demonstrated the soundness and ductility of the welded seams.

The very large attendance at this exhibition and conversazione and the great interest in new welding processes shown by the visitors was a welcome encouragement to the Branch Committee, and similar events are likely to follow from time to time.

INTERNATIONAL INSTITUTE OF WELDING

1960 Annual Essembly

The 1960 Annual Assembly of the IIW will be held from 12th to 18th June at Liège, on the invitation of the Belgian Institute of Welding.

The programme of this Assembly will not include a Public Session but, in addition to the usual programme of Commission meetings, lectures will be given on the subject of Welding Very Thick Materials. Four Commissions will also organize colloquia with a limited attendance, as follows: the 'Gas Welding' Commission on metallization; the 'Testing, Measurement and Control of Welds' Commission on the control of welds on plastics; the 'Residual Stresses and Stress Relieving' Commission on the measurement of stresses and stress relieving on thick plates; and the Commission on 'Behaviour of Metals Subjected to Welding' on a theme that will be announced later.

Future Assemblies

The Governing Council has accepted invitations from the United States of America and the Norwegian delegations to hold the 1961 and 1962 Assemblies in New York and Oslo respectively.

OTHER SOCIETIES

Canadian Welding Bureau

After a lifetime of service to the welding industry, Mr. George Foster retired at the end of June from active duty with the Canadian Welding Bureau. He is to become Secretary of the Canadian Council of the International Institute of Welding, and will continue to be available to the Bureau on a consulting basis.

Mr. Foster entered the welding industry with the Quasi-Arc Company in England, and later visited Europe and the Americas. At the outbreak of the second world war he joined the Welding Advisory Service of the DSIR in London. He returned to Canada at the end of the war, and later joined the Canadian Welding Bureau, which had just been formed by the Canadian Standards Association under the leadership of its present Director, Mr. R. M. Gooderham.

On his retirement, Mr. Foster received a sterling silver tray from the Directors and staff of the Bureau.

The Bureau has recently appointed Mr. J. T. Biskup as Chief Welding Engineer at the headquarters in Toronto. His main duties will be to assist fabricators of bridges, buildings and machinery to meet the conditions of the various welding codes of the Canadian Standards Association. Before joining the Bureau Mr. Biskup was Assistant Chief Engineer of Disher Steel, a Division of Dominion Structural Steel Ltd.

British Association of Corrosion Engineers

At a luncheon given under the auspices of "The Corrosion Engineer" in May, Mr. H. M. Powell, Technical Director of Cathodic Corrosion Control Ltd., and Chief Electrical Engineer of Constructors John Brown Ltd., announced the formation of this new association.

The objects of the Association are to promote the dissemination of technical information about corrosion matters, and in due course to establish suitable qualifications for corrosion engineers, and to standardize terminology and techniques of corrosion control.

Details can be obtained from the Hon. Secretary, at 97 Old Brompton Road, London, S.W.7.

Conference of Classification Societies

An International Conference of Classification Societies was held in June at the offices of Lloyd's Register of Shipping. At the Conference, which was the third of its kind to take place, considerable progress was made towards arriving at substantial agreement regarding unification of regulations for hull structural steel.

Cast Iron as an Engineering Material

The British Cast Iron Research Association, jointly with the Metallurgy Department of the Royal College of Science and Technology, Glasgow, is running a series of fourteen lectures at the College; they started on 22nd October and will end on 3rd December. The aim of the lectures is to instruct the engineer and designer on the metallurgy and properties of cast iron, and to indicate correct principles of design from the aspect of both the foundryman and the user of the casting.

Institute of Physics

At the Annual General Meeting of the Institute in July, Sir George Thomson (Master of Corpus Christi College, Cambridge) was re-elected President. Dr. J. M. A. Lenihan was elected a Vice-President, and Dr. J. Taylor (Hon. Treasurer) and Professor F. A. Vick (Hon. Secretary) were re-elected. Dr. V. E. Cosslett and Mr. L. Rotherham were elected as Ordinary Members of the Board.

A proposal is being made to amalgamate the Institute and The Physical Society.

Commonwealth Standards Conference

One of the interesting features discussed recently at the fourth Commonwealth Standards Conference in Ottawa concerned welded steel air receivers and pressure vessels. An attempt is to be made to align various national standards in regard to air receivers, containers, and gas cylinders. The Canadian delegation is to prepare a draft basic code to cover welded pressure vessels generally, rather than separate specifications for particular end users. There was also a recommendation for the establishment of an agreed procedure for the approval of welding operators for pressure vessel work. The U.K. delegation was asked to prepare a table of the various Commonwealth standards for steels used in pressure

vessels and to indicate which standards could be regarded as equivalent.

NEWS FROM INDUSTRY

R.C.I. to distribute Philips Industrial products

With effect from 1st November 1959, Research and Control Instruments Ltd. will become the sole distributors in the United Kingdom for the industrial products at present marketed by its associated company, Philips Electrical Ltd. A new division has been set up by R.C.I. for this purpose. Since the specialized staff from Philips will conduct the business of the new division, there will be no break in the continuity. Customers' orders will be dealt with by the same individuals as hitherto. Fully supported by the manufacturers, R.C.I. will also take over the responsibility for the maintenance of existing Philips industrial equipment.

As from the above date all correspondence relating to Philips arc welding supplies, filtration equipment, and high-frequency heating generators should therefore be addressed to: Research and Control Instruments Ltd., Industrial Products Division, Instrument House, 207 King's Cross Road, London W.C.1. (Tel. Terminus 2877).

New Anglo-Dutch welding supplies firm

A Joint enterprise of the welding supplies firm of Interlas N.V., of Soesterberg, Holland, and Mr. Eric Courtney of Courtburn Positioners Ltd., has been set up as Interlas Ltd., of 232 Bromham Road, Bedford. Mr. H. C. van Arum (Managing Director of the Dutch company) is Chairman of the new company, and Mr. Courtney is Managing Director. The new company will import and distribute accessories manufactured by the Dutch company and will also be agents for other European manufacturers of welding transformers and other fabricating equipment.

STUB ENDS

▶ Inspection Equipment Ltd. have set up a new laboratory, equipped with an Exorel 50 X-ray set. Contract work, or odd shots, can be undertaken for the inspection of all thin sections and low-density materials.

▶ The Non-Destructive Testing Society has published the first number of a new periodical "The British Journal of Non-Destructive Testing".

▶ One of the first productions models of the Hancoline oxygen cutting machine was recently demonstrated at the 12th Engineering display of the Engineering Industries Association at the Royal Horticultural Hall, Westminster. A prototype of the machine was shown at Olympia in April.

▶ At the SBAC Exhibition at Farnborough, Sciaky Electric Welding Machines Ltd. were showing a light sandwich construction in austenitic stainless steel, in which the surface sheets had been attached to the core by thousands of minute spot welds.

▶ Mr. R. J. Wright, Export Sales Manager of Lincoln Electric Co. Ltd. since 1956, has been appointed a Director of the Company.

▶ The Annual General Meeting of the Metal and Plastic Coatings Association will be held in London on 1st December 1959.

▶ Constructors John Brown Ltd. have been awarded a contract from the East Midlands Gas Board for the installation of a 50 mile long high-pressure pipeline between the coke-ovens at Scunthorpe to Lincoln and Gainsborough. The pipeline will be of all-welded construction, made up of 12 in. and 8 in. dia. pipes.

▶ Lloyd's Register of Shipping has opened offices at Bahrain (Mr. A. T. Mitchell) and at Khorramshahr, Iran (Mr. G. J. Atkins).

DIARY

2nd Nov.—West Wales—"*Class I fusion welded mild steel pressure vessels*" by A. H. Briscoe, and colour film (Swansea Technical College, 7.0 p.m.)

3rd–6th Nov.—Institute of Welding—Joint Autumn Meeting with the Société des Ingénieurs Soudeurs (54 Princes Gate, S.W.7.)

3rd Nov.—East of Scotland—"*The 250 ft diameter radio telescope at Jodrell Bank*" by C. N. Kington. Joint with Institution of Structural Engineers. (Adelphi Hotel, Edinburgh, 6.15 p.m.)

4th Nov.—East Wales—"*Locked-up stresses distortion and welding procedure*" by E. Flintham (S.W. Institute of Engineers, Cardiff, 7.0 p.m.)
Manchester—"*Fabrication of the Bradwell heat exchangers*" by B. K. Twigg and A. R. Muir (College of Technology, 7.15 p.m.)

5th Nov.—North Eastern (Tyneside)—"*The safe use of radioactive sources in shipbuilding and engineering industries*" by R. Bentley (Mining Institute, Newcastle upon Tyne, 7.0 p.m.)

6th Nov.—South Western—Welding Forum (Gloucester School of Technology, 7.15 p.m.)
Inst. Struct. Eng. (Lancs. and Cheshire Branch)—"*The New BS.449*" by L. E. Kent.

9th–13th Nov.—Institute of Welding, School of Welding Technology—Course D.2/1 "Welding design and construction in aluminium alloys".
Sheffield—Talk and film on the Berkeley Nuclear Power Station project (Grand Hotel, 7.15 p.m.)

11th Nov.—Liverpool—"*Welding in warship construction*" by W. R. Seward. Joint with Liverpool Metallurgical Society. (International Library, William Brown Street, 7.30 p.m.)
South London—"*Welding from the viewpoint of Lloyd's Register of Shipping*" by G. M. Boyd (54 Princes Gate, 7.30 p.m.)

12th Nov.—Eastern Counties—"*Fatigue in welded constructions*" by R. Weck (Colchester)

13th Nov.—Birmingham—"*Reinforced pressure vessels*" by P. J. Palmer (Grand Hotel, 7.30 p.m.)

17th Nov.—East Midlands—"*Heavy-gauge resistance welding in the aircraft industry*" (College of Art, Derby, 7.15 p.m.)
Leeds—Brains trust—Open night (Great Northern Hotel, Leeds, 7.30 p.m.)

18th Nov.—North Eastern (Tees-side)—"*CO_2 welding of steel*" by G. Phipps (Cleveland Scientific and Technical Institution, Middlesbrough, 7.30 p.m.)
North London—Demonstrations of applications of stud welding, by R. W. Taylor (54 Princes Gate, 7.30 p.m.)
Preston—"*Welding problems in the atomic energy field*" by F. S. Dickinson (Harris Technical College, Preston, 7.15 p.m.)
West of Scotland—"*Welding and testing of skirt supports for spherical pressure vessels*" by J. A. Forrest (Inst. Eng. and Shipbuilders, Glasgow, 7.0 p.m.)

19th Nov.—Southern Counties—"*Applications of welding*" by O. W. Lipton (Technical College, Southampton)

25th Nov.—South London (Medway Section)—Films and talk by W. Roy (Works of Fredk. Braby & Co. Ltd., Crayford, 7.30 p.m.)

27th Nov.—Wolverhampton—Paper on strain gauging (Wulfrunians' Club, Lichfield Street, Wolverhampton, 7.30 p.m.)

1st Dec.—Metal and Plastic Coatings Association—Annual General Meeting.

2nd Dec.—Manchester—"*Questions about welding*" answered by panel of F. Koenigsberger, E. J. Heeley, R. Bushell, E. H. Lee (College of Technology, 7.15 p.m.)

3rd Dec.—Birmingham—Annual Dinner (Grand Hotel, Birmingham)
North Eastern (Tyneside)—"*Welding in the production of marine oil engines*" by J. A. Dorrat (Mining Institute, Newcastle on Tyne, 7.0 p.m.)

4th Dec.—Institute of Welding—Conversazione: "*I.I.W. work in hand*" (54 Princes Gate, S.W.7, 4.0–8.0 p.m.) (Tickets only)

7th Dec.—West Wales—"*Selection and uses of arc-welding processes*" by E. Flintham (Neath Technical College, 7.0 p.m.)

8th Dec.—East Wales—"*Selection and uses of arc-welding processes*" by E. Flintham (Llandaff Technical College, Cardiff, 7.0 p.m.)
Liverpool—"*Gas-shielded arc processes with consumable electrodes*" by D. B. Tait (College of Technology, Byrom Street, 7.30 p.m.)
South Western—Meeting to be arranged (Radiant House, Bristol, 7.15 p.m.)
North London (Slough Section)—"*Low temperature brazing and welding*" (Community Centre, Slough, 7.0 p.m.)

9th Dec.—South London—"*Characteristics of welding plant*" by J. C. Needham (54 Princes Gate, S.W.7, 7.30 p.m.)

APPOINTMENTS

Advertisements for Situations Vacant and Wanted will no longer be included in the News Section of the *Journal*, but will be placed, with other Classified Advertisements, on the last page of the Advertisement Section.

The rates will remain the same: 3*s.* 6*d.* a line or 30*s.* per inch depth semi-display.

For all Classified Advertisements published in the January 1960 and subsequent issues of the *Journal*, orders and correspondence should be addressed to the Advertisement Manager, 54 Princes Gate, London, S.W.7 (Tel. Knightsbridge 8556).

Copy should be sent by 6th of each month for insertion in the following month's issue.

Current WELDING LITERATURE

Book Reviews
Additions to the Institute Library
Trade Publications

CONTENTS OF PERIODICALS RECEIVED

This section is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the Bibliographical Bulletin of Welding and Allied Processes, *published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.*

Welding Journals

African Oxygen, 1959, vol. 5, June

Welding aluminium and steel (2–3)
Quarrying costs cut by hard facing, C. V. Whitehouse (16–22)
Diesel reduces welding costs (23–25)

Arcos (Belgium), 1958, vol. 36, No. 141

Tests for resilience after ageing, J. Lemoine and J. Bienfait (3681–3701)
Machines for transformers of 75,000 and 150,000 kVA (3703–3704)
Hydraulic action diesel locomotives (3705–3709)
Asphalt storage tanks, R. Devogelaere (3710–3712)

Australian Welding Journal, 1959, vol. 2, No. 8, April

Welding on the city tunnel (7–9)
Hidden arc welding of pressure vessels for the chemical industry, B. C. Pile (11–13)
Fabrication of tubular steel structural joints, K. J. Fulton (15–18)
Welding and brazing in atomic reactor construction (19–20)
New electronic tracer follows pencil lines (21)
Cutting stainless steel by the mile (23–24)
Aluminium and steel fabrications for the United Kingdom Atomic Energy Authority (25–28, 32)

Canadian Welder, 1959, vol. 50, June

Industry leaders comment on welding's half-century (8–12)
The early days of welding, Walter Shaw (14–15)
Welding machines of the future (20)

Canadian Welder, 1959, vol. 50, July

Characteristics of high-current DC welding power sources, R. L. Stuefen (10–12)
Fully automatic welding plant, D. Ewan (14–15)

Esab Review (Sweden), No. 3–4, 1958

The introduction of automatic welding in a brazing workshop, Agnar Haeger (1–11)
Some notes on hard facing by welding, Stig Lundin (12–21)
Advice on the welding of heavy plate, M. Puschner (22–23)

Japan Welding Society, Journal, 1959, vol. 28, May

Theory and review of recent studies concerning unconsumable welding arc (1), A. Uchida (4–10)
Hard facing by spray welding of colmonoy alloys, T. Naiki and H. Anzai (11–16)
The effects of weld thermal cycles upon mechanical properties of the weld heat-affected zone of low alloy steels, M. Inagaki (16–19)
Weldability of notch ductile steel, S. Morita and others (20–26)
On the fundamental study of the multiple electrode submerged arc welding (Report 1), O. Takagi (27–30)
Over cladding mild steel with stainless steel, T. Nannichi (31–33)
Studies on welding of Al-steel, S. Morita and others (34–41)
On the secondary current measurement of the three phase frequency type resistance welding machine, T. Nakamura and T. Sumi (42–46)
Studies on cold pressure welding (Report 1), T. Saito and K. Yamaji (47–54)
Cracking on the brazing of steel, S. Morita and others (55–59)

Lastechniek (Holland), 1959, vol. 25, July

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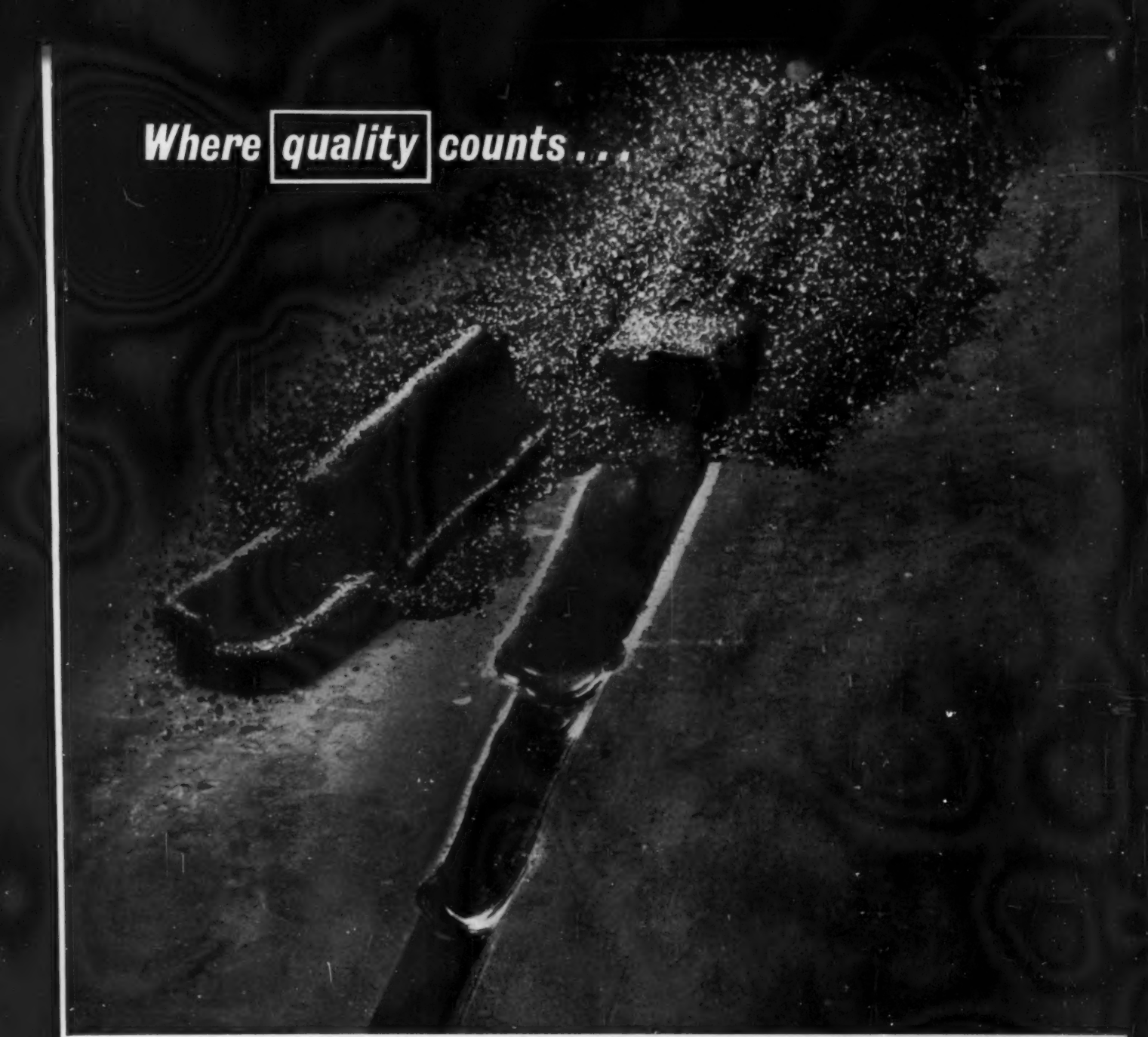

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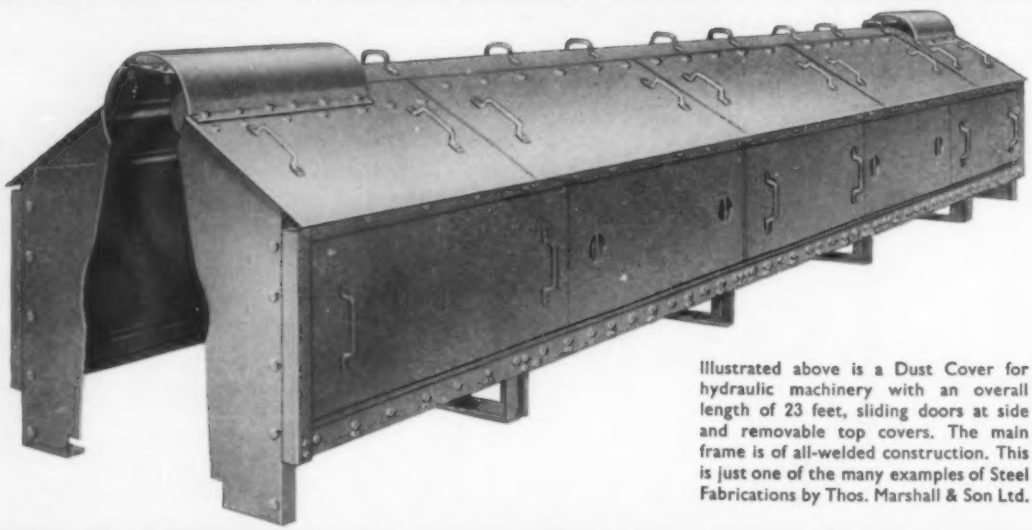

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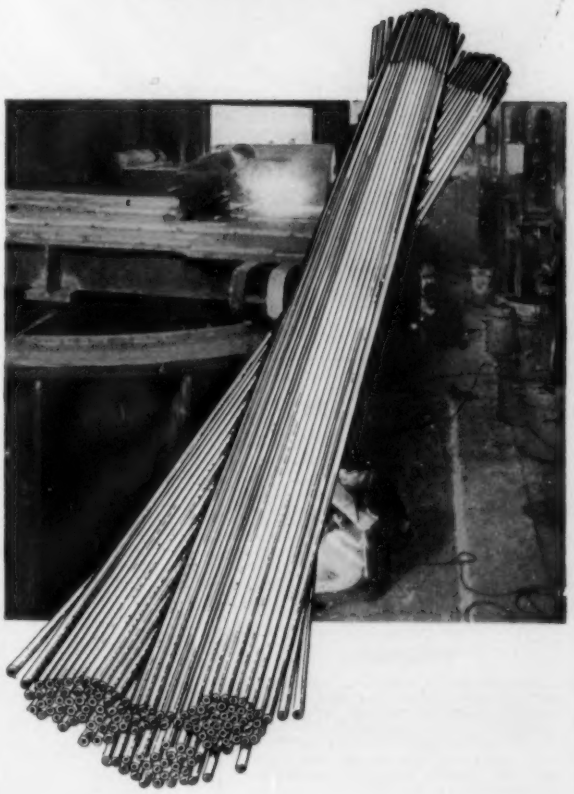

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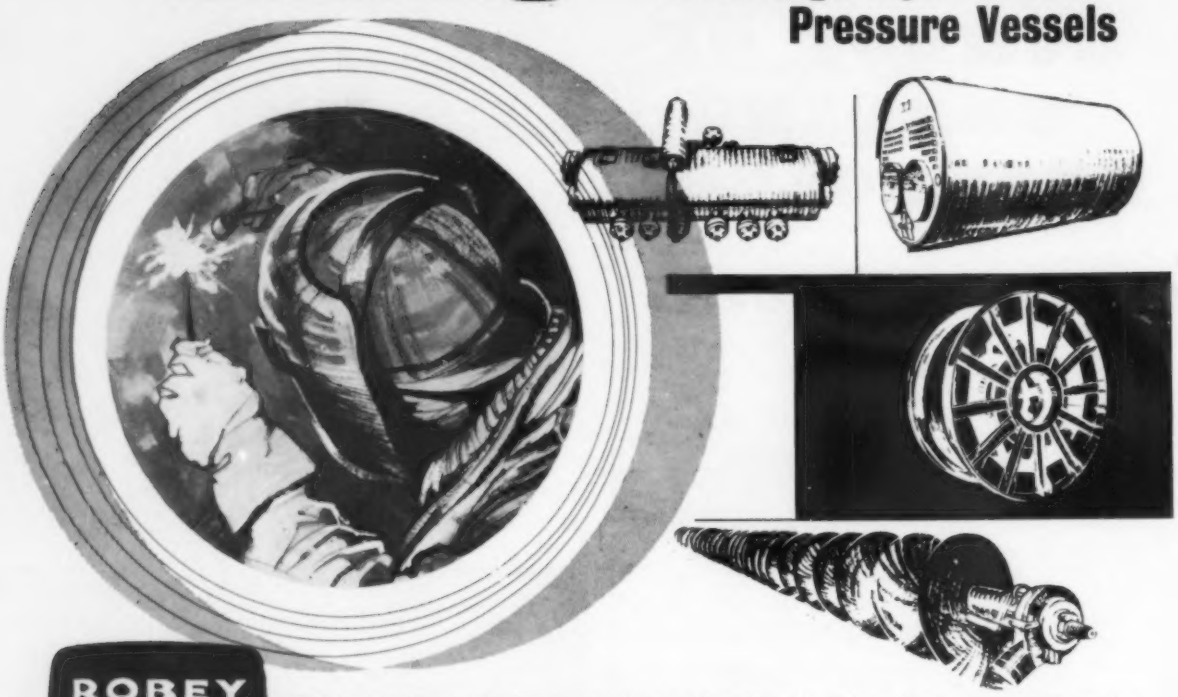

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All other matters relating to advertisements for this section of the News should be addressed to the Executive Editor, 6 Ridge End, Hook Hill Lane, Woking, Surrey (Tel. Woking 2981).

Copy should be sent by 6th of each month for publication in the following month.

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bare wire

CO_2 welding machine

Philips AUTOMATIC CO_2 *bare wire* welding process is now available for immediate delivery in Britain. With this machine you can speed up mass production of welded parts, for example main chassis members, bottled gas cylinders, car wheels. And you can get welds protected from nitrogen and hydrogen by an atmosphere of CO_2 — which costs only a fraction of the price of argon. The absence of coating reduces the absorption of hydrogen, too.

- Welds very wide range of steel grades.
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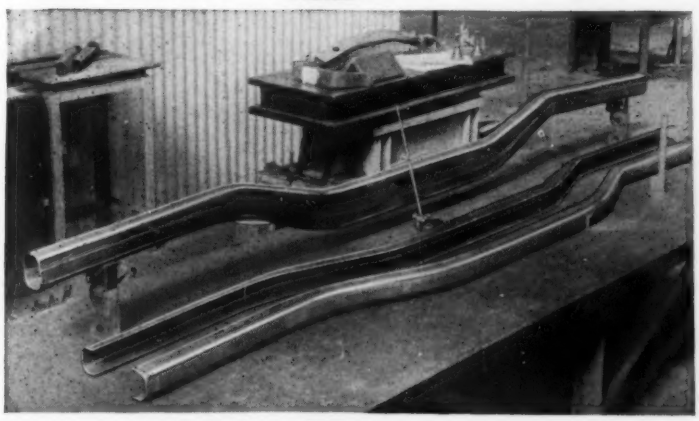
- Cuts labour costs by welding faster, requiring little attention in repeat operations.
- Welds are homogeneous with deep and even penetration.
- Arc is self-regulating . . .
- Nitrogen and hydrogen content low — no nitrogen porosity.



Component parts and finished vehicle chassis side member welded by Philips CO_2 process. *(Photo by courtesy of John Thompson / Motor Pressings Ltd.)*

Philips Automatic CO_2 welding machine

provides automatic wire and CO_2 feeds. Travelling carriage moves along rails at speed set by operator. Water-cooled nozzle independent of main water supplies. Single control lever engages wire feed, switches on carriage motor and arc.

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